Department of Primary Industries
Department of Regional NSW

Southern NSW research results 2022

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

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an initiative of Southern Cropping Systems

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Front cover images: main: farming systems field experiment, Wagga Wagga Agricultural Institute (WWAI), Mathew Dunn; inset left: pulse variety experiment, racing the light to finish sowing ahead of predicted rain – Rankins Springs, Karl Moore; inset centre: canola field experiment, 2021 – Yanco Agricultural Institute, Mathew Dunn; inset right: rice phenology sample collection, Tina Dunn.

Back cover images: inset left: cereal phenology experiment – Dirnaseer, Dr Felicity Harris; canola research paddock, 2021 – WWAI, Mathew Dunn; inset right: field day, 2021 – WWAI, Mathew Dunn.

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Foreword

NSW Department of Primary Industries (NSW DPI) welcomes you to the Southern NSW research results 2022. This book has been produced to increase awareness of research and development (R&D) activities undertaken by NSW DPI in the southern mixed farming region of NSW. It delivers the outcomes of these activities to our stakeholders including agribusiness, consultants and growers.

This document is a comprehensive, annual report of NSW DPI's R&D activities in southern NSW. The book includes research covering agronomy and physiology, weeds, farming systems, crop protection, water and irrigation in southern NSW.

NSW DPI, in collaboration with our major investment partner the Grains Research and Development Corporation (GRDC), is at the forefront of agricultural research in southern NSW and the largest research organisation in Australia. Our R&D teams conduct applied, scientifically sound, independent research to advance the profitability and sustainability of our farming systems.

The Department's major research centres in the southern region of NSW are Wagga Wagga, Yanco and Condobolin where our team of highly reputable research and development officers and technical staff are based. The regional geographic spread of the research centres allows for experiments to be replicated across high, medium and low rainfall zones with Yanco providing the opportunity to conduct irrigated experiments in cotton and rice supported by Cotton Research and Development Corporation and AgriFutures co-investment with NSW DPI.

NSW DPI's research program includes the areas of:

- plant germplasm improvement
- agronomy and crop management
- plant product quality and market access
- productive and sustainable use of soil
- productive and sustainable use of water
- integrated pest management within production systems
- livestock genetic improvement
- integrated weed management
- animal productivity and value chain efficiency and meat quality
- intensive livestock industries
- feedbase productivity
- drought preparedness, response and recovery
- climate adaptation and mitigation
- agriculture landuse planning
- energy solutions.

The following papers provide an insight into selected R&D activities taking place in the southern region. We hope you will find them interesting and valuable to your farming system or the farming system clients you work with.

Special thanks to all the authors and editorial officers for their willingness to contribute to this publication and I acknowledge the effort in reviewing the diverse range of papers.

We acknowledge the many collaborators (growers, agribusiness and consultants) that make this research possible. We also encourage feedback to help us produce improved editions in future years.

Deb Slinger
Director Southern Cropping
On behalf of the Southern Research and Development Teams
NSW Department of Primary Industries

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Seasonal conditions 2021

Michelle Miller

Seasonal Conditions Coordinator, NSW DPI Climate Branch

Climate summary

Condobolin Agricultural Research and Advisory Station

Minimum temperatures at Condobolin were below the long-term monthly average (LTA) for most of 2021 (Figure 1). June, July and August were exceptions in the growing season with minimum temperatures being equal to or above the LTA.

Maximum temperatures during the first part of the 2020–21 fallow period (November 2020 to January 2021) were initially higher than the LTA in November, and then dropped below the LTA. Maximum temperatures remained below the LTA for the remainder of the fallow period (February to May 2021), which reduced the soil water evaporation potential through this period. The 2021 winter maximum temperatures closely followed the LTA up to September, after which maximum temperatures dropped below the LTA through spring and rose back to the LTA in December.

Generally, both the minimum and maximum temperatures were below or close to the LTA during the growing season (May to October 2021).

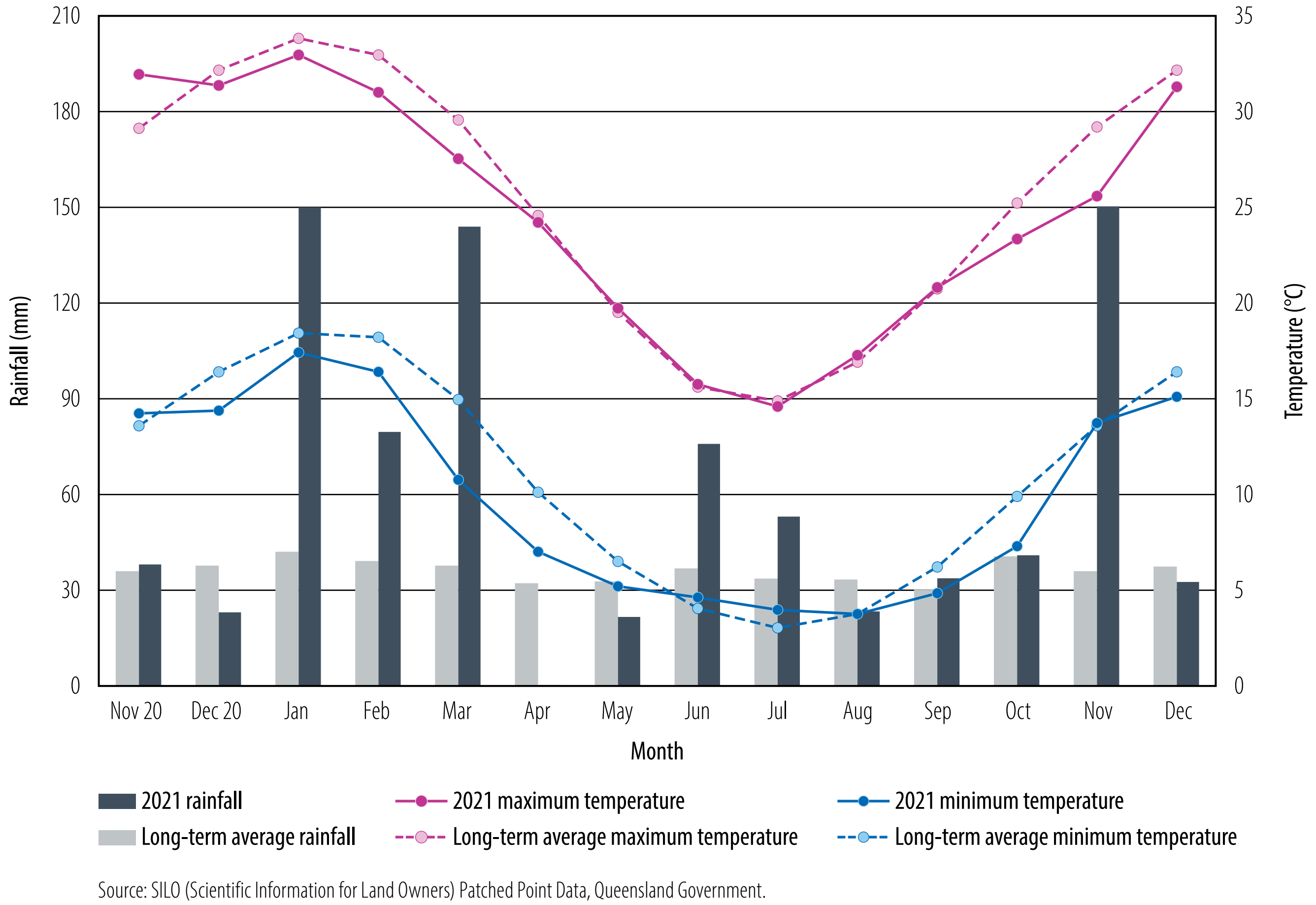


Figure 1 Average monthly minimum and maximum temperature in 2021, total monthly rainfall in 2021, and long-term averages at Condobolin Agricultural Research and Advisory Station, including the November and December 2020 summer fallow period.

Average to below average rainfall was received in the early fallow period (November to December 2020). Rainfall was well above average for January, February and March, with more than three times the monthly average rainfall received in January and March (Figure 1). This rainfall provided increased soil moisture levels in the lead up to sowing. Below average rainfall in April and May allowed access to paddocks for winter sowing to commence. Rainfall above the LTA was received early in the growing season (June and July 2021). At the end of the growing season (September to October 2021) rainfall was close to the LTA. The combination of good fallow soil moisture and growing season rainfall provided a foundation for high crop yields. November rainfall was well above the LTA providing challenging conditions for harvest.

Overall, the grain yields for winter crops were well above average because of the excellent growing season in 2021 at Condobolin.

Wagga Wagga Agricultural Institute

Minimum temperatures at Wagga Wagga were generally below the LTA for most of 2021 (Figure 2). June and July were the exceptions where minimum temperatures were equal to or slightly warmer than the LTA.

After a warm start in November 2020 the maximum temperatures during the 2020–21 fallow period (November 2020 to January 2021) were much lower than the LTA. Maximum temperatures were close to the LTA at the end of fallow period and for sowing in May and remained slightly warmer than the LTA through winter (June to August 2021). The 2021 spring maximum temperatures were close to or cooler than the LTA.

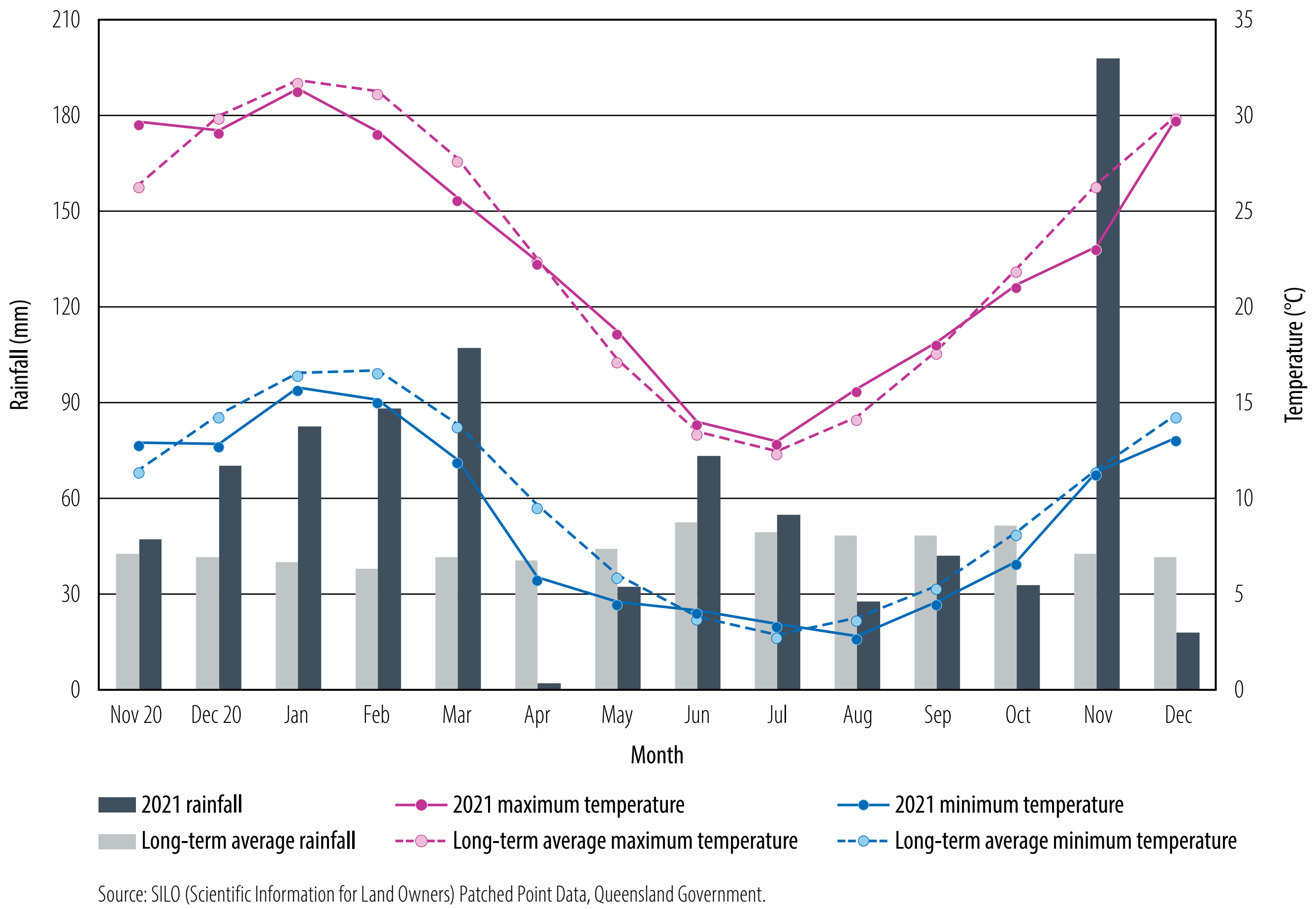


Figure 2 Average monthly minimum and maximum temperature in 2021, total monthly rainfall in 2021, and long-term averages at Wagga Wagga Agricultural Institute, including the November and December 2020 summer fallow period.

From November 2020 through to March 2021, fallow rainfall was well above average (Figure 2). This rainfall improved stored soil moisture levels before the sowing period. Below average rainfall received in April and May 2021 improved access to paddocks for sowing however patchy canola germinations were experienced in late April due to the below average April rainfall. These crops eventually recovered and performed very well as a result of the high levels of stored soil moisture at depth. Rainfall was above the LTA for June and July 2021 and then fell below the LTA for the growing season from August to October 2021. Generally, the rainfall provided a high yield potential for 2021 winter crops, although rainfall well above the LTA in November resulted in significant wheat quality downgrade and loss of yield and test weight in unharvested canola crops.

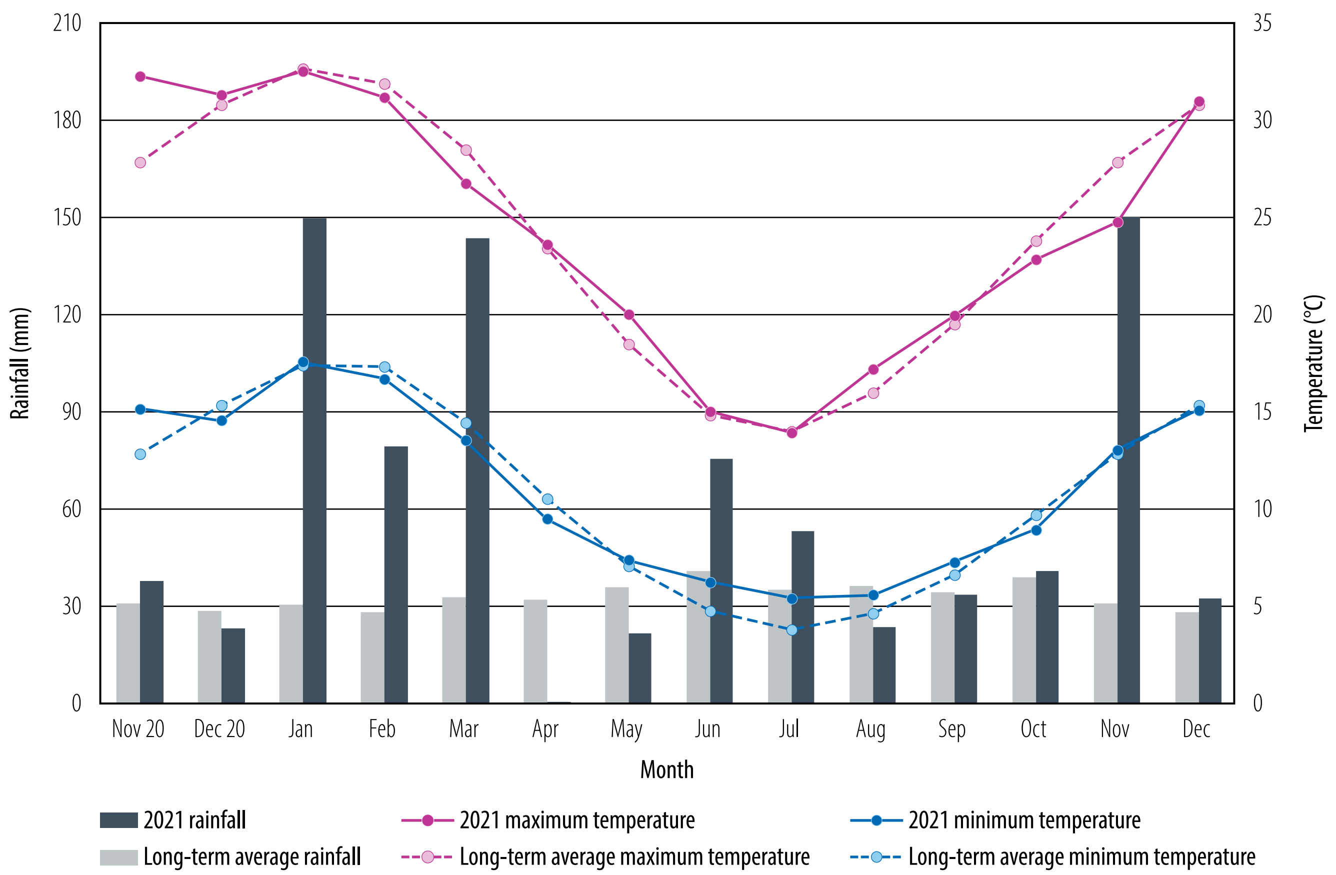
Yanco Agricultural Institute

Minimum temperatures at Yanco were close to or below the LTA for most of 2021, except for the winter period (June to August 2021) during which minimum temperatures were warmer than the LTA (Figure 3).

Following warmer than average maximum temperatures in November 2020, maximum temperatures were generally close to or below the LTA during the fallow period from January to April 2021. The cooler conditions helped preserve subsoil moisture later in the fallow period. Maximum temperatures fluctuated through the growing season (May to October) with above LTA maximum temperatures in May, close to average LTA temperatures through June and July, before maximum temperatures rose above LTA in August and September 2021.

Earlier sown cotton crops that established before the colder November weather were a long way ahead of the later sown crops and some of the later sown crops had to be resown due to very poor establishment. Wet and colder conditions made cotton establishment difficult in the spring of 2021. The wet conditions made weed control harder in drill sown rice but resulted in water saving for growers, some of whom only irrigated once before applying permanent water.

Generally, both the minimum and maximum temperatures were close to, or slightly above the LTA during the growing season (May to October 2021).



Source: SILO (Scientific Information for Land Owners) Patched Point Data, Queensland Government.

Figure 3 Average monthly minimum and maximum temperature in 2021, total monthly rainfall in 2021, and long-term averages at Yanco Agricultural Institute, including the November and December 2020 summer fallow period.

Apart from December 2020, rainfall during the fallow period (November 2020 to March 2021) was above average to well above average (Figure 3). Rainfall in February and March 2021 was well above average and provided a confident start to the growing season with high soil moisture stores. Well below LTA April rainfall and below average rainfall in May provided a drier spell to enable access to paddocks for sowing. Rainfall was above the LTA early in the growing season (June and July 2021), below average in August, and close to the LTA for the remainder of the growing season (September to October 2021).

Disease

Winter cereals

The 2021 season in southern NSW was characterised by excellent growing conditions following on from 2020. The higher rainfall and earlier sowing opportunities promoted disease development across the state. The 2021 Grains Agronomy & Pathology Partnership (GAPP) northern region crop survey showed higher levels of disease across the state. The survey data reflected the improved growing conditions with higher leaf disease levels, the necrotrophic disease such as septoria tritici bloth (STB), yellow leaf spot (YLS), spot form net blotch (SFNB) and scald were able to recover quickly in the wet 2020 season following a dry 2019 and continued to cause problems in 2021. Root diseases such as crown rot were still common and did impact grain yield in some paddocks. The "198" and "239" strains of wheat stripe rust were the dominant pathotypes in 2021 causing large areas of susceptible varieties to require fungicide protection.

In total 998 diagnostic activities were provided across NSW, between Wagga Wagga and Tamworth cereal pathology groups. A combined northern region report on the diagnostic activities was produced for publication at the 2022 NSW Grains Research and Development (GRDC) updates by Brad Baxter, Dr Steven Simpfendorfer and Dr Andrew Milgate. This was a sustained increase in diagnostic/advice delivered through the 2 GAPP projects in 2021 compared to 165 in total during 2019. The wheat stripe rust epidemic was the dominant feature of enquiries, with other leaf pathogens such as STB and YLS also showing significantly higher levels in grower paddocks across southern NSW. Wheat streak mosaic virus was detected at higher levels in 2021 due to the conducive conditions for mite survival over the 2020 fallow period.

Winter pulse and oilseed

Compared to 2020, the levels of disease (foliar and root) observed in pulse and oilseed crops across the region was reduced. This reflected the pattern of rainfall across NSW in 2021. Above average rainfall in the first half of 2021 allowed crops to be sown on time into reasonable moisture, although rainfall was well below average in April and early May. Consistently wet conditions through June, July and early August favoured early foliar disease establishment, such as blackleg and sclerotinia of canola, chocolate spot of faba bean and ascochyta diseases of field pea and chickpea. Continued wet conditions in winter made the application of foliar fungicides difficult in many districts. However, rainfall patterns changed in late August with drier than average conditions in September and October. The result was significantly lower levels of foliar disease compared to 2020.

Key observations

- Wet conditions across the region in winter 2021 favoured the early build up and spread of ascochyta diseases of field pea and chickpea. In some instances, wet conditions prevented the application of foliar fungicides and resulted in significant yield losses.
- Sclerotinia disease was observed in narrow-leaf lupin and chickpea crops, although not at the same severity as 2020. Whilst the level of disease was reduced, even low levels of sclerotinia disease can enable the fungus to continue to persist in cropping paddocks and cause disease in future years.
- Chocolate spot was frequently observed and reported in faba bean crops across the region, especially medium to high rainfall districts. The high frequency of wet days throughout June, July and early August favoured early establishment and spread of the disease. However, drier conditions

in September and October reduced further development of chocolate spot and prevented significant yield loss in crops.

- Botrytis grey mould was observed for the first time in many years in narrow-leaf lupin crops in southern NSW in 2020. In 2021, the disease continued to be observed in many narrow-leaf lupin crops across the region, but not at the same level of severity.
- High levels of blackleg were observed in canola crops across the region. Every canola crop inspected during crop surveys had blackleg present causing varying levels of injury.
- Wet conditions in winter did result in waterlogging and root disease injury in some districts. Lupin and chickpea are susceptible to waterlogging injury and the onset of root rot diseases compared with more tolerant pulses such as field pea and faba bean.
- Compared to 2020 very low levels of virus infection were observed in pulse and oilseed crops across the region.

Despite reduced levels of disease being observed in commercial crops in 2021, pathogen inoculum levels would have been maintained for the 2022 season. This makes crop monitoring and disease control important for grain producers in 2022.

Acknowledgements

Thank you to contributors Dr Mehrshad Barary (Research and Development Agronomist), David Troldahl (Leader, Summer Crops), Andrew Carmichael (Leader – Cereals South), Dr Andrew Milgate (Cereal Pathologist), Dr Kurt Lindbeck (Pulse Pathologist), and Peter Matthews (Technical Specialist Grain Services), for review.

Cereal phenology and yield responses to sowing time – Dirnaseer 2021

Dr Felicity Harris, Jordan Bathgate and Melissa Pike
NSW DPI, Wagga Wagga

Key findings

- Mild temperatures, combined with unlimited soil moisture through the season provided optimal conditions for crop growth and development, resulting in very high grain yields in 2021.
- There were significant differences in grain yield responses across sowing dates, with many newly released wheat and barley genotypes achieving higher grain yields compared with current industry benchmarks.
- The barley genotypes flowering window was 15 days earlier compared with the wheat genotypes; barley had higher yields than wheat at comparable flowering dates.
- Rain, combined with cool temperatures during the grain filling stages, had a significant effect on grain quality. There were significant genotype × sowing date interactions, with earlier sowing treatments recording lower falling numbers compared with the late May sowing.

Keywords wheat, barley, flowering, grain quality, yield, falling number, Dirnaseer, phenology, 2021

Introduction

A field experiment was conducted at Dirnaseer in 2021 to evaluate the differences between wheat and barley for phenology, grain yield and quality in response to sowing time. This paper presents the results and discusses the influence of sowing date on the phenology, grain yield and quality for 24 wheat and 12 barley varieties.

Site details

Location	Dirnaseer
Soil type	Red chromosol
Paddock history	Canola (2020), faba bean (2019)
Sowing	Direct drilled with DBS tynes spaced at 250 mm using a GPS auto-steer system.
Target plant density	140 plants/m^2.
Soil pH$_{Ca}$	5.2 (0–5 cm); 4.6 (5–10 cm); 5.0 (10–15 cm); 5.0 (15–20 cm).
Mineral nitrogen (N)	153 kg N/ha at sowing (1.5 m depth).
Fertiliser	• 100 kg/ha mono-ammonium phosphate (MAP) (at sowing). • 46 kg N/ha applied as urea on 30 June, 55 kg N/ha applied as urea on 10 August.

Weed control

Knockdown: Musta 450 (glyphosate 450 g/L) at 1.2 L/ha (23 April, before sowing).

Pre-emergent: Boxer Gold® at 2.5 L/ha, Avadex® Xtra at 1.6 L/ha and TriflurX® at 1 L/ha, incorporated by sowing at each sowing date (SD).

In-crop: MCPA LVE 570 at 630 mL/ha, Paradigm® at 25 g/ha and 0.5% Uptake® spray oil (31 May – SD1; 9 July – SD2 and SD3).

Disease and pest management

Seed: treated with Hombre® Ultra and Evergol® Energy.

Fertiliser: treated with Flutriafol (250 g/L) at 400 mL/ha.

In-crop: Fungicide sprays throughout the season were applied for all sowing dates:

- Amistar®Xtra (400 mL/ha) on 9 July
- Prosaro® 420 SC (300 mL/ha) on 10 September and 8 October
- Bumper® 625 EC (200 mL/ha) on 22 October.

Note: fungicide strategy to minimise effects from disease with variable phenology types.

Harvest dates

- 6 December (barley, all SDs).
- 8 December (wheat, SD1).
- 18 December (wheat, SD2 and SD3).

Rainfall

- In-crop (23 April–30 October): 362.6mm.
- During the grain filling period (1 October–18 December): 180 mm, including 70 mm in one event (24–27 November).

Treatments

Twenty-four wheat (Table 1) and 12 barley cultivars (Table 2) varying in phenology responses were sown on 3 sowing dates in 2021:

- SD1: 23 April
- SD2: 13 May
- SD3: 31 May.

Table 1 Expected phenology response of wheat genotypes, based on Australian Crop Breeders Ltd *An industry guide for wheat variety maturity description.*

Phenology type	Genotypes
Winter (W)	Illaboᶲ
Very slow (VS)	Sunmaxᶲ
Slow (S)	LongReach Lancerᶲ, Sunflexᶲ, Valiant CL Plusᶲ, LongReach Raiderᶲ, LongReach Stealthᶲ
Mid–slow (MS)	EGA Gregoryᶲ, Cootaᶲ, Catapultᶲ, Rockstarᶲ
Mid (M)	LongReach Trojanᶲ, Sunmasterᶲ, Suntopᶲ, Sheriff CL Plusᶲ, Sunblade CL Plusᶲ
Mid–quick (MQ)	Scepterᶲ, Boreeᶲ, Ascot
Quick (Q)	LongReach Hellfireᶲ, LongReach Mustangᶲ
Very quick (VQ)	Vixenᶲ, Borlaug 100

Table 2 Expected phenology response of barley genotypes.

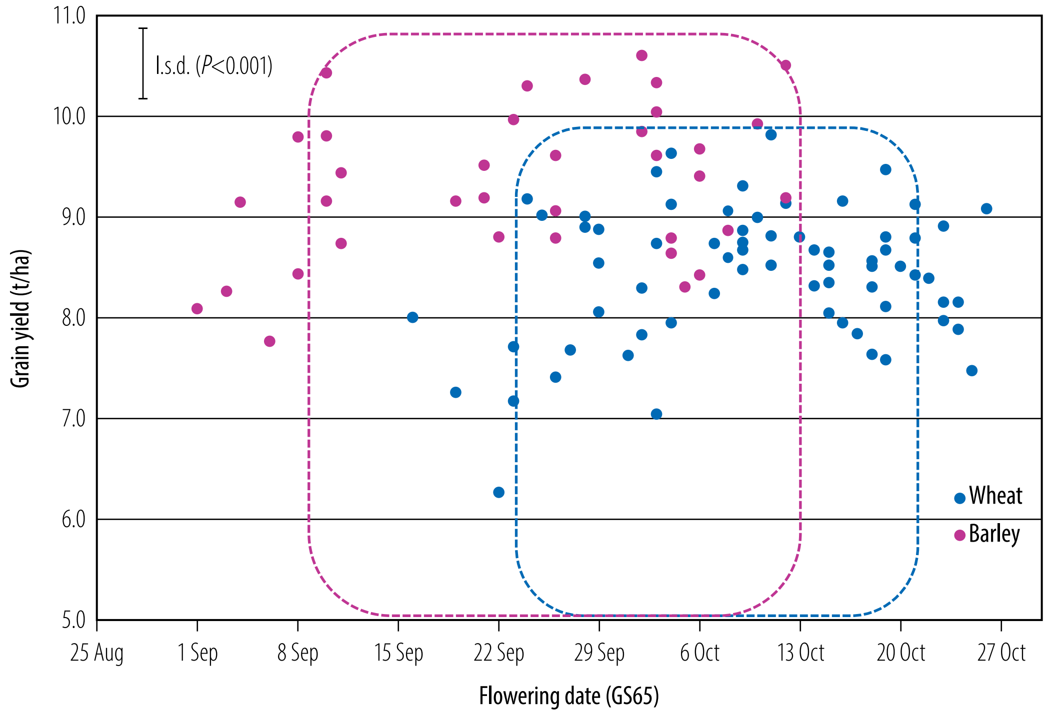
Phenology type	Genotypes
Winter (W)	Urambie⊕
Mid–slow spring (MS)	Nitro⊕
Mid spring (M)	Laperouse⊕, Yeti⊕, RGT Planet⊕, Minotaur⊕
Quick spring (QS)	Leabrook⊕, Cyclops⊕, Beast⊕, Rosalind⊕, Maximus CL⊕, Spartacus CL⊕

Results

Phasic development

In 2021, the flowering windows for wheat and barley spanned 40 and 41 days respectively. Despite this, the flowering window was 15 days earlier for barley (1 September to 12 October) than for wheat (16 September to 26 October). Barley also achieved higher grain yields than wheat at a comparable flowering date (Figure 1). This data supports previous observations that the optimal flowering period (OFP) for maximum yield potential for barley is earlier than for wheat.

There was significant variation in phenology responses to sowing date amongst the wheat and barley varieties (Figure 2 and Figure 3). Earlier flowering dates were recorded by quicker developing spring types that progressed quickly for SD1 and flowered earlier than the OFP. For example, Spartacus CL⊕ was the quickest barley variety to flower (1 September) for SD1 (23 April). However, when sown on SD2 (13 May) or SD3 (31 May), which aligns with the recommended sowing window, Spartacus CL⊕ flowered on 19 September (SD2) and 4 October (SD3), within the OFP.



Note: Blue box represents optimal flowering period (OFP) for wheat, pink box represents an indicative OFP for barley at Dirnaseer.

Figure 1 Relationship between flowering date and grain yield at Dirnaseer, 2021.

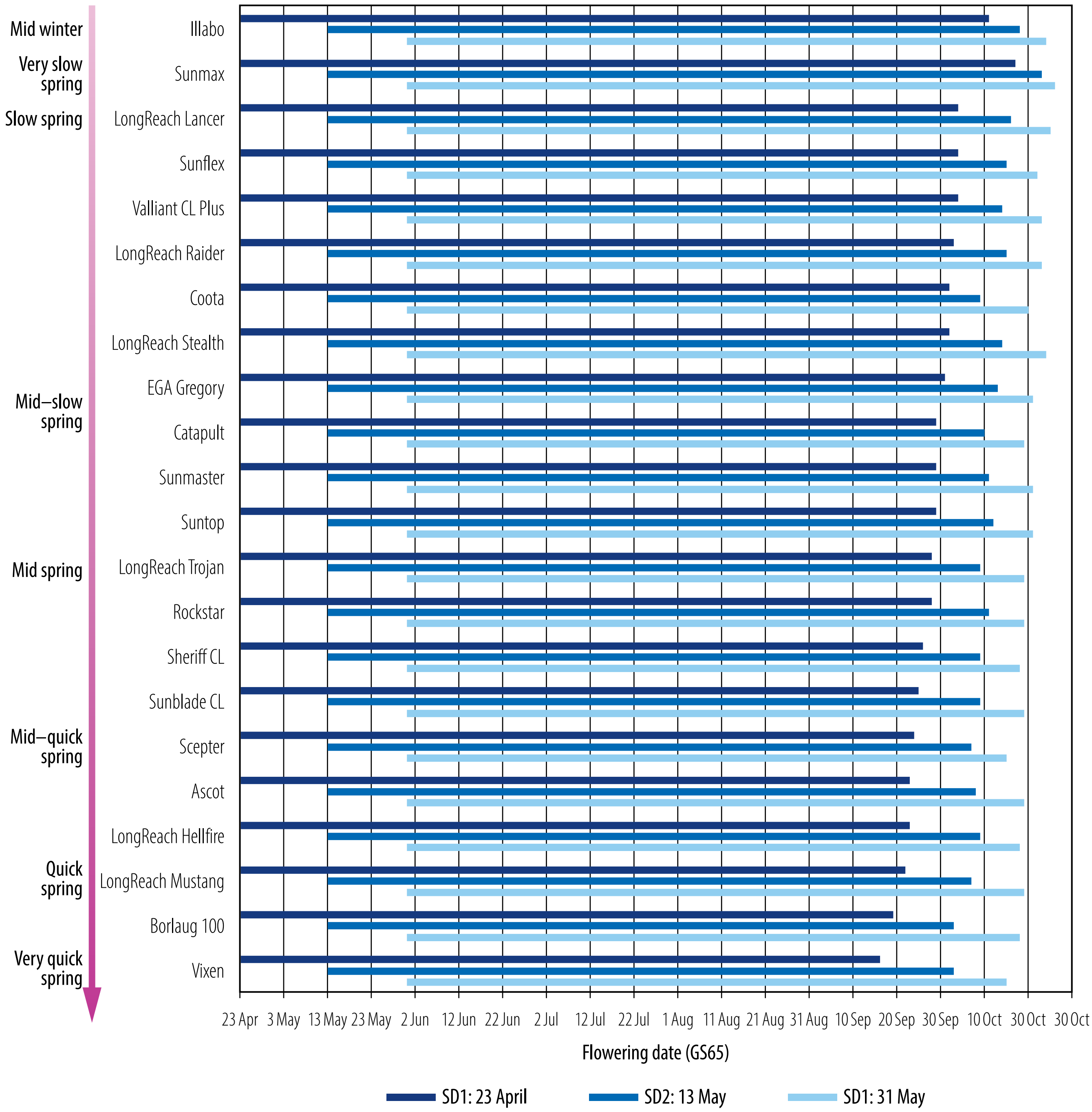


Figure 2 Wheat flowering responses to sowing time at Dirnaseer, 2021. Days from sowing to flowering (GS65) for SD1 (23 April), SD2 (13 May) and SD3 (31 May).

Grain yield

Grain yields and genotype rankings varied significantly across the sowing dates (late April to late May), with many new released wheat and barley genotypes achieving higher grain yields compared with industry benchmarks. The highest yielding wheat varieties included Boree⚷, Rockstar⚷, Valiant CL Plus⚷ and Vixen⚷, with yields greater than 9.4 t/ha. RGT Planet⚷ achieved consistently high yields for all sowing dates with the new genotypes Cyclops⚷, Minotaur⚷ and Nitro⚷ also achieving yields greater than 10 t/ha for some sowing dates.

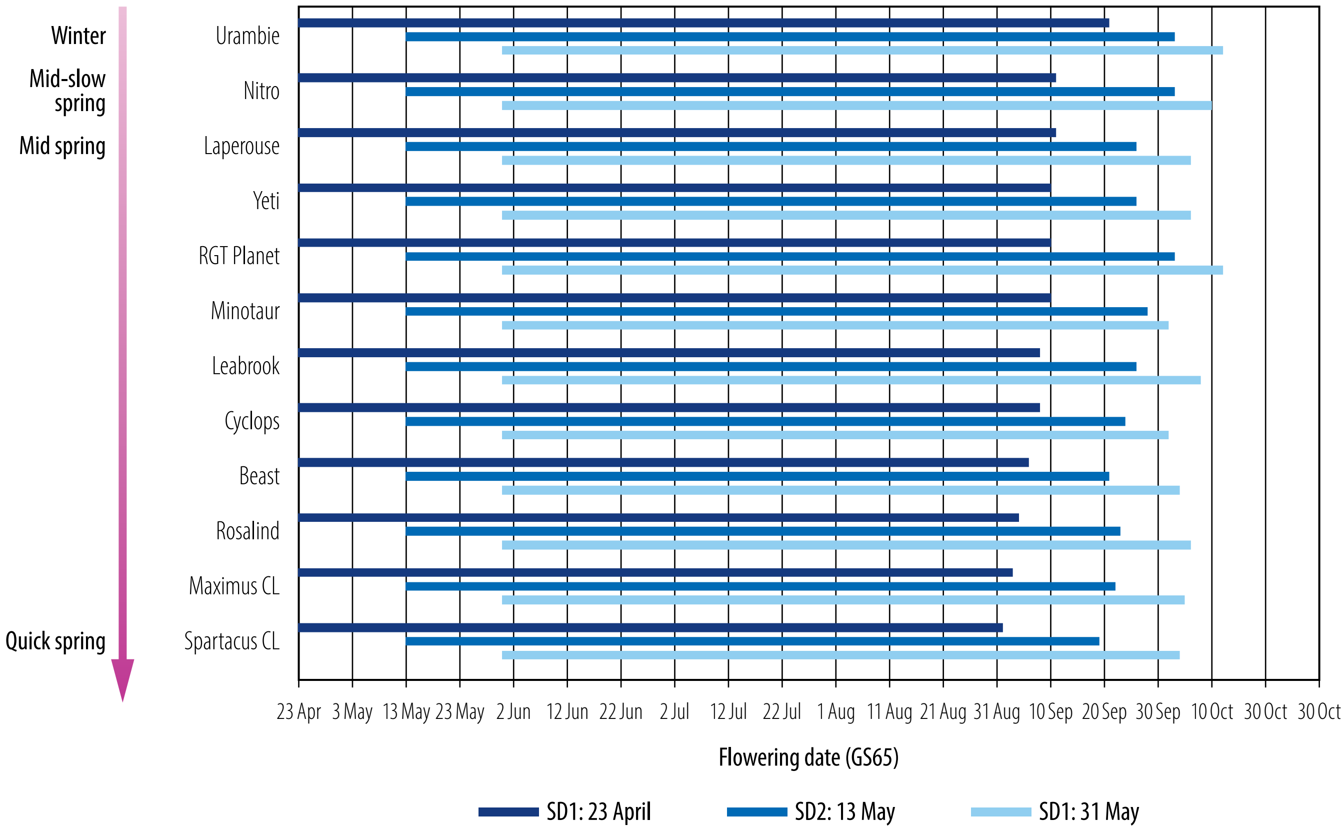


Figure 3 Barley flowering responses to sowing time at Dirnaseer, 2021. Days from sowing to flowering (GS65) for SD1 (23 April), SD2 (13 May) and SD3 (31 May).

Table 3 Grain yield for wheat and barley genotypes evaluated at Dirnaseer, 2021. *Genotype ranking for each sowing date in parentheses.*

Genotype	Grain yield (t/ha)					
	SD1: 23 April		SD2: 13 May		SD3: 31 May	
Wheat						
Ascot	7.72	(18)	9.08	(6)	8.81	(5)
Boree	8.65	(10)	9.46	(3)	9.56	(1)
Borlaug 100	7.26	(21)	7.05	(23)	8.58	(9)
Catapult	8.56	(11)	9.01	(7)	8.81	(6)
Coota	8.30	(12)	8.68	(14)	8.52	(11)
EGA Gregory	7.64	(19)	8.82	(10)	9.14	(3)
Illabo	8.83	(8)	8.52	(17)	7.90	(20)
LongReach Hellfire	7.18	(22)	8.49	(18)	7.65	(21)
LongReach Lancer	7.96	(15)	7.95	(22)	7.48	(23)
LongReach Mustang	6.27	(23)	8.26	(21)	7.59	(22)
LongReach Raider	8.75	(9)	8.66	(15)	8.16	(16)
LongReach Stealth	7.84	(17)	8.33	(20)	8.17	(15)
LongReach Trojan	8.91	(6)	8.76	(11)	8.69	(8)
Rockstar	9.02	(5)	9.84	(1)	9.48	(2)
Scepter	9.19	(2)	8.75	(12)	8.06	(18)
Sheriff CL	7.42	(20)	8.88	(9)	8.32	(14)

Genotype	Grain yield (t/ha)					
	SD1: 23 April		SD2: 13 May		SD3: 31 May	
Sunblade CL	9.03	(4)	9.32	(4)	8.12	(17)
Sunflex	9.14	(3)	8.36	(19)	8.40	(13)
Sunmaster	8.89	(7)	8.54	(16)	8.44	(12)
Sunmax	7.85	(16)	8.92	(8)	9.09	(4)
Suntop	8.07	(13)	9.16	(5)	8.81	(7)
Valiant CL Plus	9.65	(1)	8.69	(13)	7.98	(19)
Vixen	8.02	(14)	9.47	(2)	8.53	(10)
Barley						
Beast	7.77	(12)	9.20	(8)	8.65	(10)
Cyclops	9.82	(3)	10.32	(3)	10.62	(1)
Laperouse	8.75	(8)	8.80	(12)	8.43	(11)
Leabrook	8.45	(9)	9.63	(7)	8.88	(8)
Maximus CL	8.27	(10)	8.82	(11)	8.31	(12)
Minotaur	9.83	(2)	10.39	(1)	9.86	(4)
Nitro	9.45	(5)	10.06	(4)	9.94	(3)
RGT Planet	10.45	(1)	10.36	(2)	10.53	(2)
Rosalind	9.16	(7)	9.98	(5)	9.69	(5)
Spartacus CL	8.10	(11)	9.18	(9)	8.81	(9)
Urambie	9.53	(4)	9.63	(6)	9.20	(7)
Yeti	9.18	(6)	9.07	(10)	9.43	(6)
Mean (Wheat)	8.22		8.70		8.43	
Mean (Barley)	9.06		9.62		9.36	
l.s.d. (Genotype)	0.40					
l.s.d. (SD)	0.12					
l.s.d. (Genotype × SD)	0.70					

Grain quality

Favourable seasonal conditions minimised any physical grain quality effects. Screenings increased as sowing date was delayed, however they were within the industry delivery benchmark (<5%) across all varieties and sowing dates. Test weights were lower for the earlier sowing dates, however, only a few quicker developing wheat varieties (e.g. Vixen$^{\phi}$, LongReach Mustang$^{\phi}$) for SD1 were below the delivery threshold of 76 kg/hL. Barley test weights were more stable across the 3 sowing dates.

As with much of the region, the experiment site received 180 mm rain during the grain filling period (1 October – 18 December) with 70 mm in one event (24–27 November) which, combined with cool temperatures, influenced falling numbers. There was a significant genotype × sowing date interaction, with earlier sowing treatments showing lower falling numbers compared with the late May (SD3) sowing treatment (Table 1; Figure 4). Despite this, some genotypes recorded consistently high falling numbers (e.g. Wheat: Coota$^{\phi}$, LongReach Raider$^{\phi}$, and LongReach Mustang$^{\phi}$; Barley: Cyclops$^{\phi}$, Minotaur$^{\phi}$, RGT Planet$^{\phi}$, Spartacus CL$^{\phi}$ and Urambie$^{\phi}$). There were also differences between wheat and barley, with barley generally having higher falling numbers compared with wheat at similar harvest dates.

Table 4 Grain protein (GP), test weight (TWT), retention (RET), screenings (SRN) and falling number (FN) for all genotypes across sowing dates at Dirnaseer, 2021.

Genotype	SD1: 23 April 2021					SD2: 13 May 2021					SD3: 31 May 2021				
	GP (%)	TWT (kg/hL)	RET (%)	SCRN (%)	FN (sec)	GP (%)	TWT (kg/hL)	RET (%)	SCRN (%)	FN (sec)	GP (%)	TWT (kg/hL)	RET (%)	SCRN (%)	FN (sec)
Wheat															
Ascot	13.4	75.2	-	1.0	74	11.5	81.7	-	2.6	254	11.5	84.2	-	2.4	345
Boree	12.3	78.6	-	1.1	171	10.6	82.4	-	3.0	264	10.3	82.4	-	3.4	370
Borlaug 100	14.0	77.0	-	1.0	98	11.8	80.8	-	3.7	114	11.2	84.2	-	3.4	278
Catapult	12.4	79.7	-	0.9	136	10.2	83.1	-	2.4	298	10.8	82.1	-	3.2	339
Coota	12.9	79.7	-	0.6	354	11.2	82.5	-	2.5	379	10.9	83.0	-	2.7	367
EGA Gregory	11.8	81.1	-	0.7	287	11.3	82.9	-	2.5	343	11.4	84.2	-	2.2	344
Illabo	12.2	79.5	-	0.4	273	10.6	80.5	-	1.6	150	11.2	79.9	-	1.8	278
LongReach Hellfire	14.5	79.1	-	0.7	188	12.4	83.3	-	2.0	354	11.7	83.9	-	1.6	355
LongReach Lancer	12.9	77.9	-	1.0	111	11.8	82.5	-	2.2	237	11.8	83.7	-	1.4	291
LongReach Mustang	13.5	75.9	-	1.0	320	11.5	81.3	-	3.3	354	11.6	82.4	-	5.1	367
LongReach Raider	12.2	76.2	-	1.3	327	11.3	80.1	-	2.6	377	11.4	80.6	-	2.5	356
LongReach Stealth	12.5	78.3	-	1.1	108	11.3	83.0	-	2.8	325	11.5	82.9	-	1.7	328
LongReach Trojan	12.2	79.0	-	0.7	287	11.1	83.7	-	2.3	364	10.7	84.2	-	1.8	372
Rockstar	12.5	76.4	-	1.0	90	10.6	81.6	-	2.6	154	10.3	82.2	-	2.5	307
Scepter	11.9	79.7	-	0.8	158	10.9	83.5	-	2.9	345	10.4	82.8	-	3.8	346
Sheriff CL	13.3	76.2	-	0.6	120	11.4	83.0	-	1.4	304	10.9	83.3	-	2.6	285
Sunblade CL	11.9	79.5	-	1.3	162	10.7	82.2	-	3.1	321	10.7	82.5	-	3.7	329
Sunflex	12.1	80.8	-	0.9	114	11.5	82.6	-	3.3	218	11.4	83.4	-	2.9	327
Sunmaster	12.5	79.9	-	0.6	157	11.1	83.0	-	1.7	318	10.7	82.6	-	2.3	320
Sunmax	10.7	81.7	-	2.4	321	10.4	83.0	-	3.6	279	10.9	82.6	-	3.5	249
Suntop	12.2	79.6	-	1.3	171	11.0	83.2	-	1.9	289	11.0	83.0	-	2.6	297
Valiant CL Plus	12.1	81.5	-	0.6	192	11.2	84.5	-	1.3	296	11.2	83.8	-	1.9	272
Vixen	13.2	75.9	-	0.7	81	11.3	80.6	-	2.5	179	10.8	81.1	-	3.7	268
Barley															
Beast	12.2	67.0	65.5	0.6	327	11.1	66.9	66.4	0.3	364	11.5	65.9	65.0	0.6	297
Cyclops	12.2	68.2	65.8	0.7	298	11.3	67.9	65.5	0.7	351	11.0	67.7	64.5	1.0	369
Laperouse	12.4	68.3	65.3	0.8	192	11.2	68.2	67.1	0.6	196	10.5	68.0	66.7	0.7	293
Leabrook	11.3	66.8	65.4	0.6	116	11.1	66.7	65.9	0.6	301	11.0	66.6	64.9	0.6	344
Maximus CL	12.0	67.7	64.8	0.7	300	12.0	66.6	64.0	0.6	289	10.8	68.0	65.0	0.7	364
Minotaur	11.5	67.6	66.5	0.5	372	10.9	67.0	66.0	0.5	349	10.6	68.7	67.5	0.5	357
Nitro	11.2	68.3	65.5	0.8	201	10.2	68.1	67.0	0.4	335	10.2	67.6	64.3	0.9	339
RGT Planet	10.6	66.4	64.5	0.6	372	9.9	67.0	65.8	0.4	376	9.9	67.6	65.4	0.8	328
Rosalind	11.8	67.6	65.0	0.7	267	11.1	66.9	64.8	0.7	290	10.8	67.2	65.3	0.6	283
Spartacus CL	12.7	67.4	63.3	0.8	344	12.0	67.3	64.5	0.5	417	11.7	67.6	60.4	1.2	405
Urambie	10.6	66.1	58.5	2.0	362	10.7	67.1	61.2	1.2	398	11.5	67.5	57.0	1.4	394
Yeti	11.5	66.7	64.6	0.8	286	12.0	67.1	65.8	0.7	291	11.5	66.8	65.3	0.7	306
Mean (Wheat)	12.5	78.6	-	0.9	187	11.2	82.4	-	2.5	283	11.1	82.8	-	2.7	321
Mean (Barley)	11.7	67.3	64.6	0.8	286	11.1	67.2	65.3	0.6	330	10.9	67.4	64.3	0.8	340

Genotype	SD1: 23 April 2021					SD2: 13 May 2021					SD3: 31 May 2021				
	GP (%)	TWT (kg/hL)	RET (%)	SCRN (%)	FN (sec)	GP (%)	TWT (kg/hL)	RET (%)	SCRN (%)	FN (sec)	GP (%)	TWT (kg/hL)	RET (%)	SCRN (%)	FN (sec)
l.s.d. (Genotype)	0.4	0.7	1.4	0.5	30										
l.s.d. (SD)	0.1	0.2	0.1	0.2	9										
l.s.d. (Genotype × SD)	0.6	1.2	2.4	0.8	52										

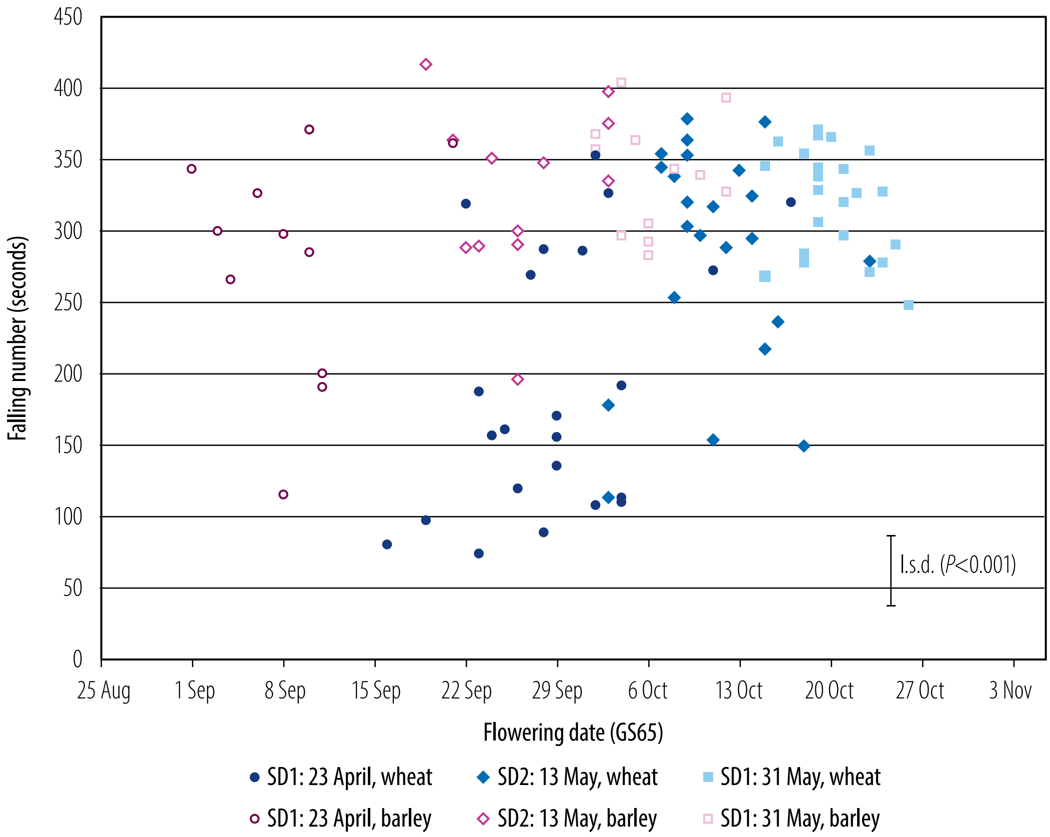


Figure 4 Relationship between flowering date and falling number response for wheat and barley genotypes across 3 sowing dates at Dirnaseer, 2021.

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The effect of a cool temperature treatment during grain filling on falling number as an indicator of late maturity alpha-amylase (LMA) presence in wheat

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Cereals

Key findings

- Late maturity alpha-amylase (LMA) is a genetic defect, commonly observed in Australian wheat breeding germplasm, that can cause low falling numbers (FN) at grain receivals.
- Twenty-four cultivars considered to range in susceptibility to LMA expression were subjected to a simulated 'cool shock' temperature treatment under controlled conditions (24 hours of 23 °C day/19 °C night, then 48 hours of 16 °C day/11 °C night) during a critical period of grain filling and were tested for FN for an indication of LMA expression.
- Under controlled conditions (without 'cool shock' temperature treatment), 71% of the cultivars tested exceeded a threshold FN of 250 seconds. In comparison, the effect of the 'cool shock' temperature treatment reduced the proportion of cultivars exceeding the FN threshold to 42%.
- In general, the FN response of the cultivars to the cool shock reflected their anticipated LMA sensitivity. A simulated cool shock treatment under controlled conditions could provide a rapid phenotyping methodology to identify wheat germplasm with high LMA susceptibility, earlier in a breeding program.

Keywords late maturity alpha-amylase, wheat, temperature shock, controlled environment, glasshouse

Abbreviations

LMA	late maturity alpha-amylase	FN	falling number
PHS	pre-harvest sprouting	DPA	days post-anthesis
l.s.d.	least significant difference	cv.	cultivar

Introduction

Late maturity alpha-amylase (LMA) is a genetic defect that is widespread in Australian wheat breeding germplasm. High levels of alpha-amylase in mature wheat grain can result in a low falling number (FN) at grain receivals. Grain with a low FN is considered unsuitable for a wide range of end-product applications (Derera 1989; Barrero et al. 2013) and is downgraded resulting in an economic loss for growers. Traditionally, a low FN has been indicative of pre-harvest sprouting (PHS) or frost damage (Mares and Mrva 2008), but LMA and the associated occurrence of high levels of alpha-amylase in grain also occurs in the absence of PHS or frost damage. This is thought to be associated with short periods of low temperature (i.e. cool shock) during grain filling (Mares and Mrva 2014). The presence of LMA restricts genetic gains in breeding programs and consumes valuable breeding resources. Currently 20–50% of breeding lines are rejected due to high LMA expression, which is often not able to be identified until late in the breeding process (Armstrong et al. 2019; Mrva and Mares 2001).

Previous research has shown an interaction between alpha-amylase expression, cool temperature shock timing, and other environmental parameters (Mares and Mrva 2014). The conditions of the controlled environment experiments described in the literature often do not mimic daily temperature variations experienced in the field and, as such, critical temperature thresholds for expression of LMA under field conditions remain unclear.

The aim of this experiment was to develop a better understanding of a cool temperature shock on the expression of LMA which represented field conditions under controlled conditions. A cool shock treatment was derived from temperature variations normally found in the field during a critical window of seed maturity. Cultivars considered to represent a range in LMA expressions were examined to quantify the effects of genotype (G) × environment (E) interactions on LMA expression and to help define a method for screening for genotypic predisposition for LMA expression in wheat lines earlier in a breeding program.

Methodology

Glasshouse conditions

Cultivars of wheat (*Triticum aestivum* L.) identified as likely to differ in their level of LMA expression (Table 1 [unpublished data, Armstrong and Mares 2021]) were grown in pots in a glasshouse (located at Wagga Wagga Agricultural Institute, Department of Primary Industries) with non-limiting moisture and nutrients. Two seeds were sown in 60 × 60 × 150 mm square pots and vernalised at 4 °C under low light for 4 weeks to saturate any cold requirements in the different cultivars. Plants were then transferred to the glasshouse and provided with supplementary lighting (16-hour days) to synchronise any remaining differences in their phenology patterns due to photoperiod responses. This was done to enable targeted temperature treatments at the same growth stage of the wheat cultivars. Temperatures were recorded using data loggers and are summarised in Table 2.

Controlled environment temperature treatments

The LMA cool shock cycle was based on daily temperature cycles that were predicted to trigger LMA development in cropping areas where LMA risk is high. Using the Armstrong et al. (2019) predictive model a daily temperature cycle was developed and applied to the plants until they had passed their window of sensitivity (>35 days post-anthesis [DPA]). The temperature cycle was developed to meet the model's four conditions:

1. at least one day with a daily maximum >24 °C
2. any 3 days with a daily maximum temperature ≤18 °C (need not be consecutive; hence the cycle implemented 2 days cool, before returning to one high day)
3. for conditions 1. and 2. to be applied during the LMA sensitivity window
4. temperature regime to reflect a daily temperature cycle.

Individual tillers were tagged at anthesis (first anthers extruded, Zadoks growth stage 61). Cultivars were transferred at 12 DPA to one of 3 controlled environment chambers located at Charles Sturt University, Wagga Wagga. Each growth chamber (Conviron – PGW40) was set to an acclimation period to replicate glasshouse conditions before a gradual introduction to the LMA cool shock cycle (Figure 1). The LMA cool shock treatment was a looped cycle of 24 hours of 23 °C day/19 °C night, then 48 hours of 16 °C day/11 °C night for 10 days during the critical grain filling period for LMA sensitivity with a 16-hour photoperiod. Untreated controls remained in glasshouse conditions at 23 °C day/14 °C night throughout the entire experiment. Plants were transferred from the controlled environment chambers back to the glasshouse for grain ripening.

Laboratory testing

Grain samples were harvested at maturity and milled for laboratory testing. Grain was tested for FN using the Hayberg-Perten methodology (Perten 1964) for an indication of LMA expression. The FN test is adequate to determine alpha-amylase presence in controlled environment experiments, where there is no confounding effect of weather damage or PHS (D. Mares, 2020 pers comm).

Statistical analysis

The experiment was a randomised design with 2 treatments (control or cool shock temperature), blocked by replication with 3 replicates. Duplicates of each cultivar × treatment were sown, so that each treatment was represented in 2 pots (subplots), these were each sampled and tested for FN, then averaged for the treatment before analysis. An analysis of variance (ANOVA) was performed using GenStat software (VSN International, UK). The least significant differences at 5% level were used to assess whether means were statistically different from each other.

Treatments

Wheat cultivars

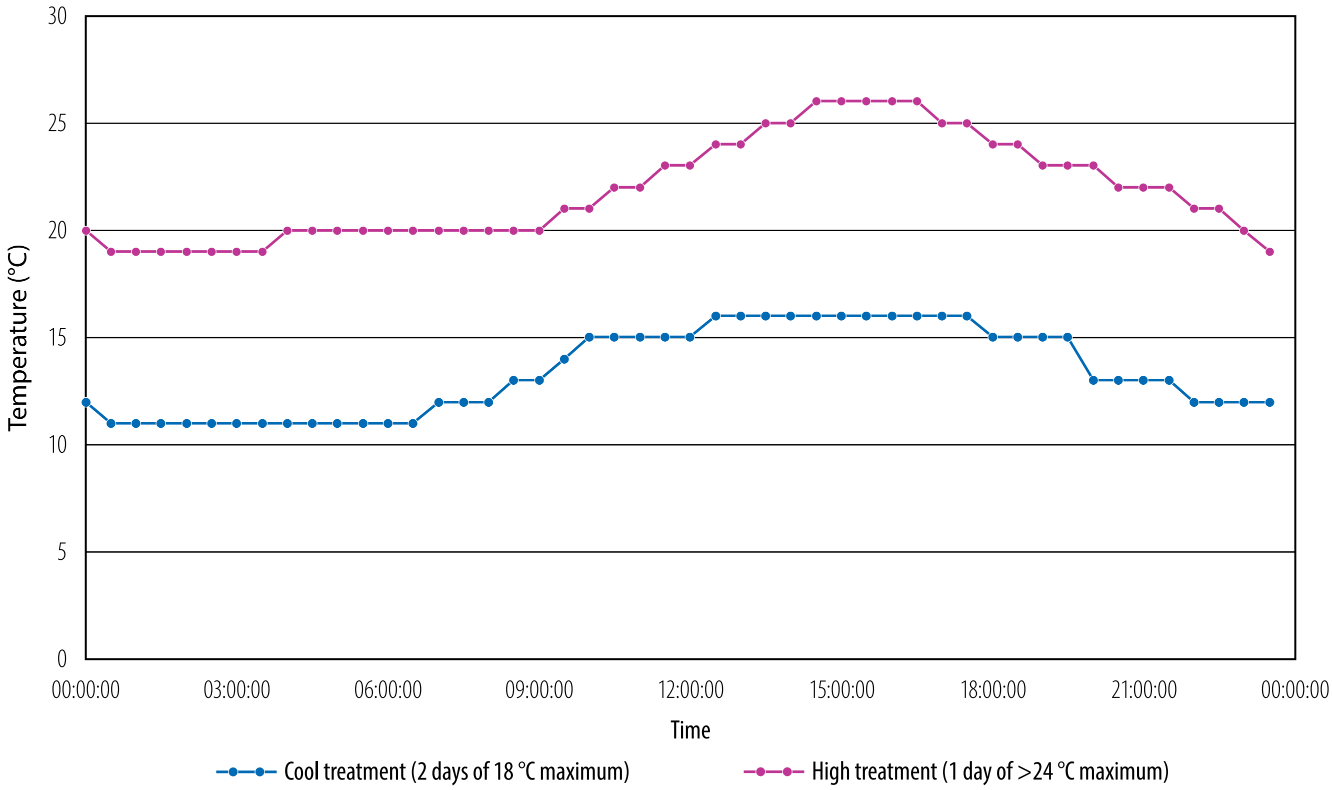
Table 1 Wheat cultivars used in experiment with associated LMA expression levels (unpublished data, Armstrong and Mares, 2021).

LMA rating	Wheat cultivar
Nil detected	Calingiri, EGA Gregory[PBR], Espada[PBR], Hartog, Janz, LongReach Cobra[PBR], LongReach Spitfire[PBR], Mace[PBR], Magenta[PBR], Yitpi[PBR]
Very low	Corack[PBR], Emu Rock[PBR]
Low to moderate	LongReach Lancer[PBR], Westonia, Wyalkatchem[PBR]
High	AGT Katana[PBR], BD159, Chara[PBR], Cranbrook, Kennedy, RAC655
Very high	Reeves, Seri, Spear

Temperature treatments

Table 2 Temperature and humidity conditions from vernalisation treatment, glasshouse and controlled environment room.

Growth stage	Sowing to 2-leaf (Z12)		2-leaf (Z12) to anthesis (Z61)	12 to 35 DPA (LMA sensitivity window)	Grain ripening
Experimental stage	Vernalisation chamber		Glasshouse	Controlled environment (cool shock)	Glasshouse
Temperature conditions (°C)	Minimum	5	14	See Figure 1	13
	Average	5	17		20
	Maximum	8	23		34
Humidity conditions (%RH)	Minimum	78	42	51	41
	Average	96	72	75	67
	Maximum	100	100	100	94



Note: The cycle repeated 2 days of cool and one day of high to meet model conditions from Armstrong et al. (2019) model parameters.

Figure 1 LMA cool shock cycle applied during LMA sensitivity window in controlled environment growth rooms.

Results

Falling number and the effect of the cool shock treatment

Falling number of the cultivars grown under the control conditions (23 °C day/14 °C night during a critical window of the grain filling period) ranged from 78 seconds to 395 seconds and from 62 seconds to 396 seconds under the controlled environment conditions designed to imitate a cool shock (a cycle of 24 hours of 23 °C/19 °C, then 48 hours of 16 °C /11 °C during the critical grain filling period). The FN of cultivars differed significantly (P<0.05; Table 3) and the main effect of the cool shock treatment was significant (P<0.05) causing an average decline in FN of 50 seconds. The FN of 71% of cultivars grown in control conditions exceeded 250 seconds, the grain quality threshold required at grain receivals to avoid a quality downgrade (GrainCorp Ltd 2021). However, when subjected to the cool shock treatment, only 42% of the cultivars exceeded this FN threshold.

Susceptibility of individual cultivars to low falling number outcomes

Large variability was associated with the average FN of the expected LMA susceptibility groups. It was clear that at least part of the large error term was associated with the intrinsic variability of FN assessments which, across all cultivars, had an average coefficient of variance of 22%.

In general, the FN response of the cultivars to the cool shock reflected their anticipated LMA sensitivity. However, there were a few exceptions:

- Cultivars that returned high FN results under both conditions were comprised mainly of cultivars categorised as having nil to low susceptibility to LMA. However, cv. Kennedy, which was expected to have a high susceptibility to LMA expression, had a high FN value under both conditions indicating that it might not be susceptible to LMA under these screening methods.
- Seri and BD159, cultivars considered to be susceptible to LMA and categorised as having high or very high LMA susceptibility, had low FN values under both control and cool shock conditions. These cultivars were considered to be 'risky' and likely to produce LMA regardless of conditions.

- Two cultivars (cv. Corack[Φ] and Janz) which were expected to be of very low and nil LMA susceptibility respectively, had low FN values under both conditions. During the glasshouse stage of the experiment, before temperature treatments were imposed, sterile florets were observed in all replications of these varieties. The unknown stress that caused the sterility could explain the lower FN and quality in these cultivars.

Table 3 Falling number (seconds) of 24 cultivars grown under either control or cool shock conditions. *The LMA susceptibility rating of each cultivar is listed.*
Values in ***bold*** *show treatments with a low FN value where LMA is assumed to be present.*

Genotype	LMA susceptibility rating	Falling number (seconds)		FN % change (% change of treated compared with control)
		Control	Cool shock temperature cycle	
Reeves	Very high	285.8	**148.8**	−48
Seri	Very high	**86.5**	**67.7**	−22
Spear	Very high	318.8	**219.2**	−31
BD159	High	**78.2**	**62.0**	−21
Chara	High	**199.0**	**135.7**	−32
Cranbrook	High	**206.7**	**131.7**	−36
AGT Katana	High	301.5	**235.5**	−22
Kennedy	High	318.0	333.8	5
RAC655	High	327.5	**116.3**	−64
LongReach Lancer	Low to moderate	362.7	332.0	−8
Westonia	Low to moderate	333.2	261.7	−21
Wyalkatchem	Low to moderate	308.7	**213.0**	−31
Corack*	Very low	**131.7***	**77.3***	−41*
Emu Rock	Very low	391.0	**243.8**	−38
Calingiri	Nil detected	**232.0**	276.7	19
LongReach Cobra	Nil detected	342.3	303.5	−11
EGA Gregory	Nil detected	317.8	**194.2**	−39
Espada	Nil detected	305.5	395.7	30
Hartog	Nil detected	273.3	259.8	−5
Janz*	Nil detected	**235.3***	**211.8***	−10*
Mace	Nil detected	278.3	331.5	19
Magenta	Nil detected	356.0	**244.2**	−31
LongReach Spitfire	Nil detected	295.5	300.0	2
Yitpi	Nil detected	372.2	374.8	1
Mean		277.4	227.9	
l.s.d. ($P = 0.05$) Genotype		72.51		
l.s.d. ($P = 0.05$) Coolshocktemp.		20.93		
l.s.d. ($P = 0.05$) Genotype × coolshocktemp.		102.54		

* These values show treatments where the result is believed to have been compromised due to a sterility issue at anthesis from unknown causes that occurred prior to receiving the temperature shock.

Summary

The aim of this experiment was to develop a better understanding of cool shock as an environmental trigger for LMA expression under controlled environment conditions. When subjected to cool shock conditions during the LMA sensitivity window (12–35 DPA) there was a higher incidence of low FN results among cultivars.

Cultivars considered to represent a range in LMA susceptibilities were examined to quantify the effects of genotype (G) × environment (E) on LMA expression. It was found that in most cases, cultivars rated as having nil to low LMA susceptibility maintained their FN when subjected to a cool shock treatment. Cultivars considered as having a high to very high LMA susceptibility were found to be at risk of a low FN under both conditions tested.

The results indicated that a cool shock treatment during the sensitivity window could provide a technique to identify wheat germplasm with high LMA susceptibility earlier in a breeding program. However, direct measurement of LMA levels (e.g. LMA ELISA test) would be preferable given the higher variability of FN results. A sound understanding of genotypic susceptibilities to LMA would be an invaluable tool for informing breeders and growers of LMA risk and the choice of cultivar for growing environments.

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Rhizosheath formation can improve wheat crop survival in a false break

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Key findings

- Wheat varietal selection and/or management for large rhizosheaths might improve the chances of crop survival by more than 60% in prolonged false break conditions.
- Across various rainfall and false break scenarios, varieties with large rhizosheaths produced 42.5% more tillers and 52.4% fewer necrotic leaves than the alternative varieties.

Keywords wheat, rhizosheath, false break, autumn break, establishment

Introduction

Roots of young seedlings gently dug up from the soil have a small layer of adhering soil. Neither persistent shaking nor rinsing with water will remove the layer. These are the rhizosheaths (Figure 1), first described by Volkens (1887) on grasses from the Egyptian desert and later Price (1911) demonstrated their occurrence on several perennial grass species native to the sandy deserts of South Africa. Rhizosheaths are a feature of xerophytic (plants that need very little water) grasses. This experiment investigated whether rhizosheath formation in wheat can help buffer the effects of false breaks and reduce plant seedling death.

Figure 1 Rhizosheaths occur throughout the angiosperms (Brown et al. 2017) including wheat.

Experiment details

Location	Glasshouse environment
Soil type	• Kandosol (collected from Wagga Wagga Agricultural Institute: latitude 35° 5′ S, longitude 147° 35′ E). • Vertosol (collected from the Leeton Field Station: latitude 34° 36′ S, longitude 146° 21′ E).

Soil preparation/pot size	• Each soil type was dried in the dehydrator at 105 °C for 48 hours, and then ground to produce grains capable of passing through a 2 mm sieve mesh. • The soil was reconstituted to achieve 40% of the field capacity of each respective soil type. • The soil was then packed into PVC tube pots (10 × 30 cm) to a bulk density of 1.3 grams per cubic centimetre (g cm^{-3}).
Experiment design	Split-split plot design with 6 replicates.
Rhizosheath measurement	Rhizosheaths were measured at the end of the simulated false break for each treatment unit. The seedling was lifted out and gently shaken by hand until all bulk soil was removed and weighed to obtain the plant fresh weight. After weighing, the root system was excised at the root/shoot interface. The shoot was weighed to obtain data on biomass (fresh weight) of the above-ground parts. The below-ground parts (root and adhering soil) were transferred to a 250 mL plastic container containing 200 mL of water and kept overnight to loosen soil from the roots. Roots were then washed clean and the rhizosheath size was measured on a dry weight basis to remove differences in soil water content that might have persisted due to the applied rainwater treatment. The soil washed from the roots was captured in a container and placed in a dehydrator at 50 °C for a week to dehydrate. The soil was then weighed to obtain the rhizosheath size in grams of dry soil.

Treatments

Variety

- Halberd (high) and Westonia (low) rhizosheath-forming lines.
- Untested commercial varieties (Mace$^{\Phi}$, Scepter$^{\Phi}$, Beckom$^{\Phi}$, LongReach Flanker$^{\Phi}$).

Autumn break rain

Defined as the first significant rain of the winter growing season and signals the start of the growth period (Delloitte 2017). Rainwater was applied to represent various amounts of autumn break rain. Treatment units (pots) were watered with 5 mm, 10 mm, 15 mm, and 25 mm.

False break

Defined as a period of drought which follows an autumn break and leads to the widespread death of establishing seedlings (Chapman and Asseng 2001). The following false break durations were applied: 14 days, 28 days, 42 days and 56 days after sowing.

Results

Rhizosheath formation

Figure 2 shows the 2 soil types used in the experiment and Figure 3 shows rhizosheaths measured in the kandosol for the 6 wheat varieties after 56 days growth with 5 mm of autumn break rainfall and no follow-up rain.

Rhizosheath formation in the vertosol was largely driven by the amount of autumn break rain, while in the kandosol it was the length of the false break that was most influential (Table 1). In both soil types, the variety effect was small but highly significant ($P \leq 0.001$) indicating options for varietal selection. Importantly, while the variety × soil moisture interactions were only marginally significant, the variety × false break interactions were highly significant ($P<0.001$). This relationship indicates that wheat varieties might respond similarly to the amount of autumn break rain, but differ significantly in how long they can survive before follow-up rain occurs.

Red kandosol from Wagga Wagga

Heavy, self-mulching clay (vertosol) from Leeton

Figure 2 Soil types used for the experiment.

Figure 3 Rhizosheath size in wheat seedlings after 56 days growth with 5 mm autumn break rainfall in kandosol.

Table 1 Mean squares and F-probability values for rhizosheath size measured in the vertosol and kandosol soil types.

Source of variation	Degrees of freedom	Vertosol			Kandosol		
		MSq	*P*-value	Etasq (%)	MSq	*P*-value	Etasq (%)
Replication	5	2.01	0.806	0.05	78.32	0.063	0.63
Variety	5	25.98	0.001	0.66	402.90	<0.001	3.26
Whole plot error	25	4.40	0.820	0.56	32.29	0.399	1.30
Rainwater	3	3700.94	<0.001	56.80	408.63	<0.001	1.98
Variety × rainwater	15	11.98	0.012	0.92	61.24	0.063	1.48
Sub-plot error	90	5.43	0.705	2.50	35.81	0.167	5.21
False break	3	415.37	<0.001	6.38	11939.70	<0.001	57.89
Variety × false break	15	15.70	<0.001	1.21	186.32	<0.001	4.52
Rainwater × false break	9	344.60	<0.001	15.87	202.30	<0.001	2.94
Variety × rainwater × false break	45	17.51	<0.001	4.03	40.05	0.100	2.91
Residual	360	5.98	–	11.02	30.73	–	17.88

The split-split plot model was analysed in r (https://cran.r-project.org/).

Variety-specific effects

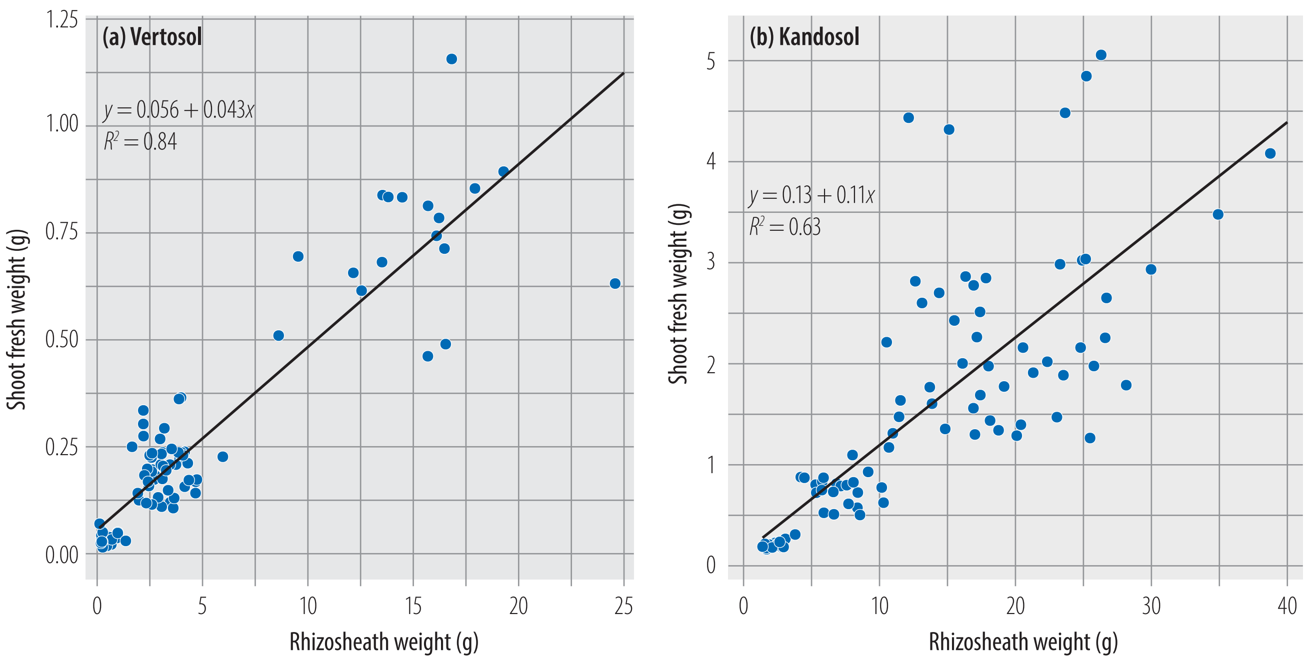
Significant variety-specific effects were found for rhizosheaths on the 2 different soil types. Across environments (false break × rainfall) Halberd had a significantly larger rhizosheath than Westonia in the vertosol. In the kandosol, LongReach Flanker(d) had a significantly larger rhizosheath than Westonia.

These differences were associated with faster growth (leaf area) and seedling survival (tiller survival) across the range of simulated false breaks that lasted up to 56 days.

This led to the question of whether varietal selection can help buffer the effects of false break conditions and reduce plant seedling death. The ability to survive a prolonged false break (more than 28 days) was measured by calculating the percentage of wilted and necrotic (dead) leaf sections per plant. In the vertosol, Halberd (large rhizosheath) produced 42.5% more tillers than Westonia (small rhizosheath) and the difference in necrotic leaves was also statistically significant (*P*-value = 0.013) with Halberd showing 52.4% fewer necrotic leaves than Westonia. Leaf necrosis was not observed in the kandosol experiment and wilting was only observed in the 56 day false break treatment; varietal differences were not significant (*P* = 0.20).

Regression analysis determined the predictive ability of rhizosheath size on seedling establishment across the 2 soil types. Shoot fresh weight was used as a measure of seedling establishment and in the analysis was fitted as the dependent variable. In both soil types the relationship between rhizosheath size and seedling establishment was positive and highly significant (*P*-value: <0.001).

Simple linear regression showed that shoot fresh weight in the vertosol increased by 43 g/plant for every unit increase in rhizosheath size (Figure 4). The coefficient of determination (R^2), which measures how differences in one variable can be explained by the difference in a second variable, was 84%. This implies that in this soil type wheat seedlings that produced larger rhizosheaths are ~84% more likely to survive a false break than those producing smaller rhizosheaths. Similarly, in the kandosol, for every unit increase in rhizosheath size, shoot fresh weight increased by 110 g/plant. The standardised regression coefficients for both soil types were 0.82 and 0.92 respectively, indicating that variety and/or management practices that increase rhizosheath size by one standard deviation unit will increase seedling survival in a false break by a ratio of almost 1:1.



Note: Data were from 6 varieties grown with 4 levels of simulated autumn break rainfall and 4 lengths of false break duration.

Figure 4 Regression of rhizosheath weight with shoot fresh weight of wheat seedlings on 2 different soil types.

Summary

- Rhizosheaths were found to explain between 63% and 84% of seedlings ability to survive false break conditions depending on the soil type. This does not suggest a cause–effect relationship, but implies similarity of response to declining water availability.

- Root size might be a significant factor, but varietal differences in root length were not significant in the vertosol ($P = 0.42$) or the kandosol ($P = 0.12$).
- Root hairs have been reported as potentially important contributors to rhizosheath formation (Marin et al. 2021), but their role remains controversial (Cai et al. 2021).
- Overall, the conclusion is that varietal selection and/or cultural management for large rhizosheaths might improve the chances of crop survival by more than 60% in a false break.

Cereals

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Improving canola harvest management decisions with remote sensing

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Key findings

- Using advanced predictive modelling approaches, we have successfully used both satellite and drone-based multispectral imagery to predict canola maturity parameters to a high degree of accuracy (seed colour change, root mean squared error – RMSE of <10%).
- Simple normalised difference vegetation index (NDVI) based regression modelling was unable to account for location- and variety-induced variation resulting in significantly higher prediction errors than when using more advanced predictive modelling approaches.
- Significant potential exists for using this technology in a canola windrow-timing-decision support tool that would overcome the many challenges of current industry practice. However, additional investigation is required to validate the performance of this technology application across multiple seasons and further progress modelling approaches.

Keywords canola, maturity, harvest, windrow, remote sensing, 2021, Wagga Wagga, Yanco

Introduction

With an Australian annual average production of 3 million tonnes, canola is a valuable break crop and an important option to diversify and complement the traditionally cereal-dominated systems in Australia. Windrowing the crop before harvest is a common practice used to manage the risk of shattering losses. However, recent work from the 'Optimised canola profitability' project (CSP000187) as well as the Grain Orana Alliance (GOA00001) has highlighted the negative effects from incorrect windrowing timing, with potential yield losses of up to 100 kg/ha/day.

A 12-month proof-of-concept project was established to address the question: Can multispectral satellite imagery be used to develop a physiological maturity/seed colour change predictive model that is accurate and precise enough to improve on-farm canola windrow and desiccation timing decisions? This paper presents a brief snapshot of the results from this project in the 2021 season.

Site details

Locations	• Wagga Wagga Agricultural Institute, Wagga Wagga, NSW • Yanco Agricultural Institute, Yanco, NSW
Soil types	• Wagga Wagga: red kandosol • Yanco: red sodosol
Sowing dates	• Wagga Wagga: 15 April 2021 • Yanco: 19 April 2021

Growing conditions	Growing conditions during the 2021 canola season were favourable at both experiment locations. With post sowing pre-emergent surface irrigation at Yanco and a total January to March rainfall of 267 mm at Wagga Wagga, both sites started the 2021 season with a near full soil water profile. Water availability was not a significant yield constraint with consistent regular rainfall throughout the season at both sites. Temperatures during the growing seasons were also favourable, with no severe frosts (no days below −2.5 °C) at either site combined with mild spring temperatures (no days above 35 °C).

Treatments

Variety

Treatments were consistent between both locations and consisted of 3 different commonly grown commercial mid–fast spring canola varieties with differing heterosis and herbicide tolerance technology:

- ATR Bonito(b)
- Pioneer® 43Y92 (CL)
- HyTTec® Trophy.

Results

Canola maturity (seed colour change) progression over time

Once the seeds began to change colour, maturity progressed rapidly at both sites, with the progression from 20% to 80% seed colour change taking 8 days at Yanco and 6 days at Wagga Wagga (Figure 1). Seed colour change of 60% (start of optimum windrow timing window) was earlier at Yanco than at Wagga Wagga, with an average date of 26 October 2021 and 4 November 2021 respectively. Few significant differences between seed colour change were found between the varieties examined at both sites.

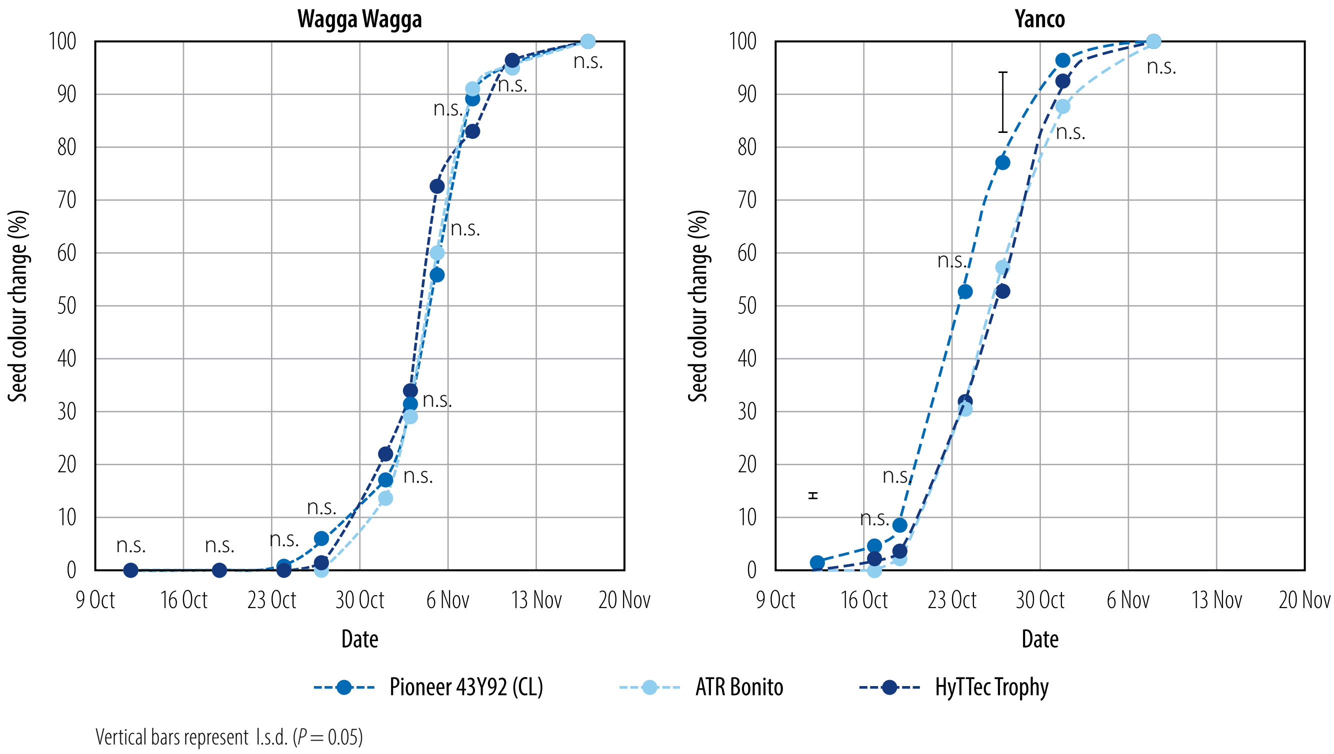

Figure 1 Seed colour change progression over time in the Wagga Wagga and Yanco 2021 field experiments.

Model development and evaluation

A range of statistical models were developed, ranging from simple regression analysis to more complicated supervised machine-learning algorithms. The aim was to predict canola maturity parameters using satellite and drone imagery with the highest possible accuracy across a range of environments and varieties. Of all the predictive modelling methods examined, a supervised machine-learning (Random Forest) method resulted in the highest prediction performance.

Random Forest (RF) regressions were performed on a range of vegetation indices derived from the RedEdge (drone), Planet (satellite) and Sentinel-2 (satellite) imagery to predict canola physiological maturity parameters. Additional variables such as weather data were also included in the modelling to assess their potential influence on prediction accuracy. The data was split into a 3:1 ratio, where 75% of data was used to train and build the model (calibration), and the remaining 25% was used to validate the model's prediction accuracy.

Root mean squared error (RMSE) was used to evaluate the model performance. RMSE is a commonly used metric to assess the relationship between values predicted by a model and observed values and, therefore, the performance of a given prediction model. In simple terms, this metric tells us the average distance between the model predicted values and the actual observed values.

The RF model developed from all 3 examined imagery sources explained the majority of the data variance (>95% for both seed colour change and seed moisture percentage) (Table 1). High prediction performance was achieved across all imagery sources with RMSE values of <10% for seed colour change and <3.5% for seed moisture.

Table 1 Random Forest model performance for canola maturity parameter predictions across a range of imagery sources.

Imagery source	Parameter	Adjusted R^2	RMSE
RedEdge (drone)	% seed colour change	0.96	7.60
	% seed moisture	0.97	2.90
Planet (satellite)	% seed colour change	0.95	8.60
	% seed moisture	0.96	2.93
Sentinel-2 (satellite)	% seed colour change	0.95	8.26
	% seed moisture	0.96	3.12

Summary

Results from this project indicate that significant potential exists for using this technology to aid canola windrow timing decisions on a broadacre scale. However, further investigation is required to assess this technology over a greater range of seasons and locations, ensuring prediction accuracy can be maintained under the highly variable growing conditions that canola producers experience.

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Albus lupin, lentil, chickpea, field pea, vetch and faba bean variety experiments – Wagga Wagga 2021

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NSW DPI, Wagga Wagga

Key findings

Lupin

- Rosetta⊕ was the highest yielding variety with 3.39 t/ha, with a later start and finish date to flowering as well as a longer flowering duration, than either Luxor⊕ or Murringo⊕.
- Luxor⊕ and Murringo⊕ were similar for grain yield, days to flowering and flowering duration in 2021.

Lentil

- PBA Jumbo2⊕ was the highest yielding variety in 2021 with 2.46 t/ha, more than 0.5 t/ha higher than all other varieties.
- PBA Bolt⊕ and PBA Kelpie XT⊕ were first to flower, with all varieties flowering within 6 days of each other.

Chickpea

- PBA Slasher⊕ was the highest yielding variety with 2.93 t/ha, with CBA Captain⊕ and PBA Boundary⊕ having similar yields.
- There was 5 days difference between the varieties in time to the start of flowering.

Field pea

- Grain yield was similar for all the field pea varieties at Wagga Wagga in 2021.
- Early flowering was seen in PBA Percy⊕ and Sturt⊕ at 101 to 103 days after sowing, and late flowering in PBA Butler⊕ at 130 days after sowing.
- Flowering duration ranged from 30 to 49 days across all varieties. PBA Butler⊕ had a very short flowering duration of 30 days while PBA Percy⊕ and Sturt⊕ flowered for over 48 days.

Vetch

- Timok⊕ grain yield was 2.14 t/ha, similar to Volga⊕ at 1.85 t/ha yet higher than the other varieties.
- Sixteen days separated the earliest flowering variety from the latest. Early flowering Studenica⊕ flowered 111 days after sowing, 16 days earlier than Morava⊕.
- Flowering duration ranged from 30 to 43 days, for Timok⊕ and Studenica⊕, respectively.

Faba bean

- Cairo⊕ was the highest yielding variety with 5.7 t/ha, with PBA Marne⊕, PBA Nanu⊕ and PBA Nasma⊕ having similar yields.
- There was 12 days difference between the first variety to flower, Doza⊕ at 96.7 days after sowing, and the last variety to flower, Nura⊕ at 109 days after sowing.

Key words Wagga Wagga, 2021, pulses, legumes, variety

Introduction

Varietal experiments were conducted to investigate establishment, crop phenology, days to flowering, flowering duration, and grain yield responses of commercially available pulse and legume varieties. All species were sown in the optimal sowing window. This paper reports the findings from these experiments.

Site details

Location	Wagga Wagga Agricultural Institute
Soil type	Red kandosol
Previous crop	Wheat
Rainfall	• Fallow (December–March): 306 mm • Fallow long-term average (LTA): 157 mm • In-crop (April–October): 204 mm • In-crop LTA: 329 mm
Fertiliser	100 kg/ha, mono-ammonium phosphate (MAP) 50% and single super phosphate (SSP) 50% (blend) (nitrogen [N]:5, phosphorus [P]:15.4, potassium [K]:0, sulfur [S]:6.25)
Sowing and harvest date	Table 1 shows the sowing and harvest dates for each crop.

Table 1 Sowing and harvest dates for the 6 species used in variety experiments at Wagga Wagga Agricultural Institute in 2021.

Species	Sowing date	Harvest date
Lupin	14 May 2021	4 December 2021
Lentil	14 May 2021	8 December 2021
Chickpea	14 May 2021	19 January 2022
Field pea	1 June 2021	7 December 2021
Faba bean	5 May 2021	4 December 2021
Vetch	15 May 2021	6 December 2021

Treatments

Varieties

Lupin: Rosetta⟐, Luxor⟐ and Murringo⟐

Lentil: PBA Ace⟐, PBA Bolt⟐, PBA Hallmark XT⟐, PBA Jumbo2⟐and PBA Kelpie XT⟐ (red) and PBA Greenfield⟐ (green)

Chickpea: PBA Boundary⟐, PBA Slasher⟐, PBA Striker⟐, and CBA Captain⟐ (desi), PBA Royal⟐ and Genesis™090 (kabuli)

Field pea: PBA Butler⟐, PBA Taylor⟐ and PBA Wharton⟐ (kaspa), PBA Pearl⟐ and Sturt⟐ (white), PBA Percy⟐ and PBA Oura⟐ (dun) and PBA Noosa⟐ (blue)

Faba bean: Cairo⟐, Doza⟐, Farah⟐, PBA Amberley⟐, PBA Bendoc⟐, PBA Marne⟐, PBA Nanu⟐, PBA Nasma⟐, PBA Samira⟐, PBA Warda⟐ and PBA Zahra⟐

Vetch: Morava⟐, Studencia⟐, Timok⟐ and Volga⟐

Results

Seasonal conditions

Above average rainfall from January to March provided adequate soil moisture for sowing on 14 May, 15 May and 1 June sowing dates. Mild environmental conditions extended throughout the growing season, which led to large crop biomass and extended flowering windows and resulted in later than usual harvest timings.

Lupin

Grain yield was significantly higher for Rosetta⑪ (3.39 t/ha), when compared with Luxor⑪ (3.02 t/ha) and Murringo⑪ (3.01 t/ha) (Table 2). Rosetta⑪ also had a higher hundred seed weight (43.9 g), than Luxor⑪ and Murringo⑪ (both under 41.0 g) (Table 2).

There were significant differences between varieties in the number of days after sowing (DAS) to the start and end of flowering. Murringo⑪ was first to flower (113 DAS) followed by Luxor⑪ (114 DAS) and Rosetta⑪ (117 DAS) which were both significantly later than Murringo⑪ (Table 2). Rosetta⑪ finished flowering significantly later (177 DAS) than Murringo⑪ and Luxor⑪ (172 and 173 DAS, respectively) (Table 2). This resulted in a longer flowering duration for Rosetta⑪ (60.5 days) compared with Luxor⑪ and Murringo⑪ (both 59 days) (Table 2).

Table 2 Albus lupin variety experiment results, Wagga Wagga Agricultural Institute, 2021.

Variety	Establishment (plants/m^2)	Days to flowering (DAS)		Flowering duration (days)	Grain yield (t/ha)	Hundred seed weight (g)
		Start	End			
Luxor	34.4	114.0	173.0	59.0	3.02	40.14
Murringo	28.0	113.0	172.0	59.0	3.01	40.68
Rosetta	35.5	117.0	177.5	60.5	3.39	43.87
Site mean	32.6	114.0	174.2	59.5	3.10	41.56
l.s.d. (P<0.05)	5.7	0.5	1.0	1.3	0.12	1.6

l.s.d. = least significant difference; DAS = days after sowing.

Lentil

PBA Jumbo2⑪ was the highest yielding variety (2.46 t/ha), out yielding all the other varieties by over 0.5 t/ha (Table 3). Lentil grain yields were lower than expected as pre harvest storms caused some pod drop and shattering. PBA Greenfield⑪ had the highest hundred seed weight (4.21 g/100 seeds), PBA Ace⑪ had a similar hundred seed weight (4.01 g/100 seeds) and PBA Hallmark XT⑪ had the lowest hundred seed weight (3.52 g/100 seeds) (Table 3).

There were significant differences in days to flowering and flowering duration between lentil varieties. PBA Bolt⑪ and PBA Kelpie XT⑪ began flowering 146 DAS, which was significantly earlier than the site average of 150 days. PBA Ace⑪ and PBA Greenfield⑪ began flowering 153 and 152 DAS respectively (Table 3). There were varietal differences in flowering duration. PBA Ace⑪ had the shortest flowering duration (42 days) followed by PBA Greenfield⑪ (43 days), PBA Hallmark XT⑪ (44 days) and PBA Jumbo2⑪ (44 days). PBA Bolt⑪ and PBA Kelpie XT⑪ both had a significantly longer flowering duration (47 days), when compared with all the other varieties (Table 3).

Pulses

Table 3 Lentil variety experiment results, Wagga Wagga Agricultural Institute, 2021.

Variety	Establishment (plants/m^2)	Days to flowering (DAS)		Flowering duration (days)	Grain yield (t/ha)	Hundred seed weight (g)
		Start	End			
PBA Ace	127.0	152.7	165.0	42.3	1.89	4.01
PBA Bolt	122.7	146.3	164.0	47.7	1.82	3.84
PBA Greenfield	129.3	152.3	165.3	43.0	1.76	4.21
PBA Hallmark XT	122.3	150.7	164.7	44.0	1.88	3.52
PBA Jumbo2	124.3	150.3	165.0	44.7	2.46	3.91
PBA Kelpie XT	118.0	146.3	164.0	47.7	1.88	3.92
Site mean	123.9	149.8	164.7	44.9	1.95	3.90
l.s.d. (P<0.05)	n.s.	1.1	n.s.	1.8	0.40	0.23

l.s.d. = least significant difference; n.s. = not significant; DAS = days after sowing.

Chickpea

PBA Slasher$^{(\phi)}$ had the highest grain yield (2.93 t/ha), which was significantly higher than all other varieties except CBA Captain$^{(\phi)}$ (2.68 t/ha). All other varieties, including the kabuli type, had similar yield (Table 4).

CBA Captain$^{(\phi)}$ was first to flower (140 DAS) and PBA Slasher$^{(\phi)}$ was last to start flowering (145 DAS) (Table 4). Mild temperatures during spring combined with adequate soil moisture led to extended flowering and pod set duration. The experiment was not harvested until mid January with flowering continuing until 2 weeks before harvest.

Table 4 Chickpea variety experiment results, Wagga Wagga Agricultural Institute, 2021.

Variety	Establishment (plants/m^2)	Days to flowering (DAS)	Grain yield (t/ha)	Hundred seed weight (g)
CBA Captain	46.1	140.0	2.68	22.78
Genesis090	43.8	142.3	2.10	31.27
PBA Boundary	44.2	143.3	2.43	21.00
PBA Royal	46.6	143.0	2.10	30.76
PBA Slasher	45.1	145.3	2.93	21.29
PBA Striker	44.6	140.7	2.29	23.40
Site mean	45.1	142.4	2.42	25.08
l.s.d. (P<0.05)	n.s.	2.3	0.47	1.46

l.s.d. = least significant difference; DAS = days after sowing; n.s. = not significant.

Field pea

All varieties had similar yields. PBA Butler$^{(\phi)}$ had the highest yield (2.79 t/ha) and PBA Oura$^{(\phi)}$ had the lowest yield (2.21 t/ha) (Table 5). There were significant differences in days to flowering. PBA Percy$^{(\phi)}$ and Sturt$^{(\phi)}$ were the first varieties to flower (101 and 103 DAS respectively). PBA Butler$^{(\phi)}$ flowered significantly later than all the other varieties (130 DAS) (Table 5).

PBA Butler$^{(\phi)}$ had a significantly shorter flowering duration (29 days) when compared with all the other varieties and PBA Percy$^{(\phi)}$ and Sturt$^{(\phi)}$ had a significantly longer flowering duration (48 days) (Table 5). Hundred seed weight varied across the varieties. PBA Percy$^{(\phi)}$ had the highest hundred seed weight (19.53 g/100 seeds) and Sturt$^{(\phi)}$ had the lowest (15.33 g/100 seeds) (Table 5).

Table 5 Field pea variety experiment results, Wagga Wagga Agricultural Institute, 2021.

Variety	Establishment count (plants/m^2)	Days to flowering (DAS)		Flowering duration (days)	Grain yield (t/ha)	Hundred seed weight (g)
		Start	End			
PBA Butler	43.0	130.0	149.7	29.7	2.79	17.22
PBA Noosa	41.0	111.0	150.7	39.7	2.44	17.87
PBA Oura	37.3	109.0	150.7	41.7	2.21	17.75
PBA Pearl	43.7	109.0	149.3	40.3	2.38	18.55
PBA Percy	42.7	101.3	150.0	48.7	2.37	19.53
PBA Taylor	39.3	114.7	150.3	35.7	2.35	17.46
PBA Wharton	46.3	112.7	150.7	38.0	2.59	16.84
Sturt	41.7	103.3	151.7	48.3	2.35	15.33
Site mean	41.9	113.9	150.4	36.5	2.43	17.57
l.s.d. (P<0.05)	n.s.	2.0	n.s.	3.0	n.s.	0.8

l.s.d. = least significant difference; DAS = days after sowing; n.s. = not significant.

Vetch

Timok$^{\phi}$ had the highest grain yield (2.14 t/ha) of the 4 varieties, Morava$^{\phi}$ had the lowest (1.5 t/ha) (Table 6). Vetch grain yields were lower than expected with pre harvest storms causing some pod drop and shattering, combined with lodging and the resultant harvest difficulties.

There were significant differences in days to flowering for all commercial varieties, Studenica$^{\phi}$ was first to flower (111 DAS), followed by Volga$^{\phi}$, Timok$^{\phi}$ and Morava$^{\phi}$ (115, 120 and 127 DAS respectively) (Table 6). Differences in days to end of flowering were also observed as Timok$^{\phi}$ (149 days) and Volga$^{\phi}$ (150 days) ended flowering significantly earlier than Studenica$^{\phi}$ and Morava$^{\phi}$ (154 and 163 days respectively) (Table 6). Flowering duration for Timok$^{\phi}$ was significantly shorter than the other varieties, ending after 29 days after starting flowering while Studenica$^{\phi}$ had a significantly longer flowering duration of 43 days (Table 6).

Table 6 Vetch variety experiment results, Wagga Wagga Agricultural Institute, 2021.

Variety	Days to flowering (DAS)		Flowering duration (days)	Dry matter (t/ha)	Maturity score*	Grain yield (t/ha)
	Start	End				
Morava	127.3	163.7	36.3	6.2	8.7	1.50
Studenica	111.3	154.7	43.3	5.5	3.3	1.75
Timok	120.0	149.7	29.7	6.2	5.0	2.14
Volga	115.0	150.3	35.3	5.9	5.7	1.85
Site mean	119.2	154.6	35.4	6.1	5.5	1.84
l.s.d. (P<0.05)	2.0	1.9	2.4	n.s.	0.80	0.25

l.s.d. = least significant difference; DAS = days after sowing; n.s. = not significant; * Maturity score: 1 = early, 9 = late.

Faba bean

Cairo$^{\phi}$ was the highest yielding variety (5.70 t/ha), with PBA Nanu$^{\phi}$ (5.49 t/ha) and PBA Nasma$^{\phi}$ (5.43 t/ha) having similar grain yields. These 3 faba bean varieties had yields significantly higher yielding than Doza$^{\phi}$ (4.90 t/ha), PBA Amberley$^{\phi}$ (4.88 t/ha), PBA Bendoc$^{\phi}$ (4.86 t/ha), PBA Samira$^{\phi}$ (4.73 t/ha) and Nura$^{\phi}$ (4.65 t/ha) (Table 7).

Significant differences were observed in days to flowering with Doza$^{\phi}$ and Cairo$^{\phi}$ being first to flower after 97 days, followed by PBA Nasma$^{\phi}$ (98 days), PBA Nanu$^{\phi}$ (98 days), PBA Warda$^{\phi}$ (99 days) and PBA Marne$^{\phi}$ (100 days) (Table 7). Nura$^{\phi}$ took 109 days to flower, significantly later than all other varieties and the site mean (Table 7). Other later flowering varieties also included, PBA Samira$^{\Phi}$ (106 days), PBA Amberley$^{\Phi}$ (105 days), PBA Zahra$^{\Phi}$ (104 days) and PBA Bendoc$^{\Phi}$ (104 days) which all flowered significantly later than the site average (Table 7).

There were significant varietal differences in flowering duration with Nura$^{\Phi}$ and PBA Nasma$^{\Phi}$ having the shortest flowering duration of 52 days and PBA Marne$^{\Phi}$ the longest with 63 days (Table 7).

Table 7 Faba bean variety experiment results, at Wagga Wagga Agricultural Institute, 2021.

Variety	Establishment score (21/7/2021)	NDVI	Vigour score† (23/8/21)	Days to flowering (DAS)	Flower duration (days)	Maturity score* (10/11/21)	Grain yield (t/ha)	Harvest score+ (29/11/21)
Cairo	8.0	0.53	9.0	97.7	59.7	3.0	5.70	7.7
Doza	8.0	0.47	8.3	96.7	60.3	4.3	4.90	8.0
Farah	7.7	0.51	8.7	102.0	60.0	4.3	4.99	6.7
Nura	7.3	0.44	8.0	109.0	51.7	5.7	4.65	7.3
PBA Amberley	7.7	0.49	8.3	105.0	54.3	6.3	4.88	9.0
PBA Bendoc	6.7	0.42	7.3	104.3	56.0	7.7	4.86	5.7
PBA Marne	7.0	0.45	8.3	100.0	62.7	2.7	5.22	8.3
PBA Nanu	7.7	0.53	8.7	98.7	56.7	3.7	5.49	7.3
PBA Nasma	7.7	0.51	9.0	98.3	51.7	2.0	5.43	7.3
PBA Samira	7.3	0.49	8.3	106.7	53.3	5.7	4.73	7.7
PBA Warda	7.3	0.48	8.7	99.3	55.7	1.7	5.04	7.7
PBA Zahra	7.0	0.53	8.0	104.7	58.7	8.3	5.18	7.3
Site mean	7.7	0.49	8.4	102.3	56.1	4.5	5.09	7.5
l.s.d. (P<0.05)	n.s.	0.07	0.8	1.4	3.2	1.5	0.45	1.7

l.s.d. = least significant difference; DAS = days after sowing; n.s. = not significant; NDVI: normalised difference vegetation index; † Vigour score 1 = low, 9 = high; * Maturity score: 1 = early, 9 = late; + Harvest score: 1 = severe lodging, 9 = erect plants.

Summary

The 2021 winter growing season was favourable for growing pulse and legume crops. Temperatures were mild and the soil moisture adequate during the crops vegetative stage, which resulted in high biomass accumulation during winter and early spring. Mild to optimal temperatures and lack of moisture stress during the reproductive period extended the grain filling duration resulting in above average yields for southern NSW. Ideal environmental conditions combined with a proactive fungicide program resulted in large crop biomass and near perfect flowering and pod fill conditions which contributed to above average yields. Seed quality was affected by several wetting and drying cycles in November prior to harvest, which is likely to reduce seed germination and the resulting plant establishment in the following crop.

Acknowledgements

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Albus lupin, faba bean, narrow-leaf lupin, chickpea, field pea and lentil variety experiments – Methul 2021

Jessica Simpson, Mark Richards, Dr Neroli Graham and Karl Moore

NSW DPI, Wagga Wagga

Key findings

Albus lupin

- There were no significant differences between varieties for grain yield and no trends between flowering and grain yield. The site mean for grain yield (2.7 t/ha) was above average.
- Murringoᶲ was the earliest flowering variety and had the longest flowering duration.
- Rosettaᶲ was the last variety to flower and had the highest hundred seed weight.

Faba bean

- PBA Nasmaᶲ, PBA Nanuᶲ and PBA Marneᶲ were the highest yielding varieties. PBA Amberleyᶲ, PBA Samiraᶲ and PBA Bendocᶲ yielded the lowest.
- There was a strong correlation between varieties that flowered early and had a shorter flowering duration, and higher yields.
- PBA Nanuᶲ and PBA Nasmaᶲ were the earliest to flower however, they had the shortest flowering duration. PBA Amberleyᶲ and PBA Samiraᶲ were last to begin flowering but flowered for up to 10 days longer.
- PBA Samiraᶲ had the highest hundred seed weight whilst PBA Bendocᶲ had the lowest.

Narrow-leaf lupin

- PBA Batemanᶲ was the highest yielding variety and had the highest hundred seed weight.
- There was a moderately strong trend that indicated yields were higher in varieties that flowered earlier. There was a moderately strong correlation between high hundred seed weight and grain yield.
- PBA Jindaleeᶲ was the latest to flower and had the shortest flowering duration, which resulted in the lowest yield and the lowest hundred seed weight.
- PBA Jurienᶲ flowered the earliest and had the longest flowering duration (8 days longer than PBA Jindaleeᶲ).

Chickpea

- PBA Slasherᶲ and PBA Strikerᶲ yielded the highest, compared with PBA Royalᶲ, Genesis™090, PBA Boundaryᶲ and CBA Captainᶲ, which yielded the lowest.
- Genesis™090 and PBA Royalᶲ (kabulis) flowered 5–6 days after desi varieties. Flowering duration was not significantly different between the varieties and there were no trends between flowering and grain yield.
- The kabuli varieties had a significantly higher hundred seed weight, compared with the desi varieties.

Field pea

- There was a moderately strong trend that indicated yields were higher in varieties that began flowering later and had a shorter flowering duration.
- PBA Percy⁽ᴰ⁾ was the earliest flowering variety, followed by Sturt⁽ᴰ⁾. PBA Butler⁽ᴰ⁾ was the last to begin flowering.
- PBA Butler⁽ᴰ⁾, PBA Pearl⁽ᴰ⁾, PBA Taylor⁽ᴰ⁾ and PBA Wharton⁽ᴰ⁾ were the highest yielding varieties. PBA Percy⁽ᴰ⁾ and Sturt⁽ᴰ⁾ were the lowest yielding varieties.
- PBA Percy⁽ᴰ⁾ had the highest hundred seed weight and Sturt⁽ᴰ⁾ had the lowest hundred seed weight.

Lentil

- The highest yielding varieties were PBA Kelpie XT⁽ᴰ⁾, PBA Jumbo2⁽ᴰ⁾, PBA Greenfield⁽ᴰ⁾ and PBA Ace⁽ᴰ⁾. Nipper⁽ᴰ⁾ was the lowest yielding variety. There were no trends between flowering and grain yield.
- PBA Blitz⁽ᴰ⁾ and PBA Kelpie XT⁽ᴰ⁾ were the earliest flowering varieties. However, varieties such as PBA Ace⁽ᴰ⁾, PBA Highland XT⁽ᴰ⁾ and PBA Hurricane XT⁽ᴰ⁾ flowered for a similar duration as PBA Blitz⁽ᴰ⁾ (53 to 54 days) despite flowering 3–6 days after PBA Blitz⁽ᴰ⁾.
- PBA Kelpie XT⁽ᴰ⁾ matured earliest and PBA Ace⁽ᴰ⁾, PBA Jumbo2⁽ᴰ⁾ and PBA Hurricane XT⁽ᴰ⁾ matured last.

Keywords Methul, 2021, pulses, legumes, variety

Introduction

Variety experiments were conducted at Methul in 2021 to evaluate the phenology and grain yield responses of 3 albus lupin, 6 faba bean, 6 narrow-leaf lupin, 6 chickpea, 8 field pea and 12 lentil varieties. Data was collected to assess each variety's establishment (scores and normalised vegetation index – NDVI), flowering dates, maturity score, grain yield and hundred seed weight.

Site details

Location	Methul
Soil type	Red clay loam
Soil pH_{Ca}	5.5 (0–5 cm), 5.4 (5–10 cm), 5.4 (10–15 cm), 6.1 (15–20 cm), 6.1 (20–25 cm), 6.1 (25–30 cm)
Previous crop	Wheat
Rainfall	• Fallow (November–March): 285 mm • Fallow long-term average (LTA): 181 mm • In-crop (April–October): 326 mm • In-crop LTA: 283 mm
Fertiliser	100 kg/ha, mono-ammonium phosphate (MAP) 50% and single super phosphate (SSP) 50% (blend) (nitrogen [N]: 5, phosphorus [P]: 15.4, potassium [K]: 0, sulfur [S]: 6.25)
Sowing and harvest date	Table 1 shows sowing and harvest dates for each species in the experiment.
Site climate	Figure 1 presents the climate data for the site.

Treatments **Variety**

Lupin

Luxor⊕, Murringo⊕, and Rosetta⊕ (albus), Mandelup⊕, PBA Bateman⊕, PBA Gunyidi⊕, PBA Jindalee⊕, PBA Jurien⊕ and Wonga⊕ (narrow-leaf or angustifolius)

Faba bean

PBA Amberley⊕, PBA Bendoc⊕, PBA Marne⊕, PBA Nanu⊕, PBA Nasma⊕ and PBA Samira⊕

Chickpea

CBA Captain⊕, PBA Boundary⊕, PBA Slasher⊕ and PBA Striker⊕ (desi), Genesis™090 and PBA Royal⊕ (kabuli)

Field pea

PBA Butler⊕, PBA Taylor⊕ and PBA Wharton⊕ (kaspa), PBA Pearl⊕ and Sturt⊕ (white), PBA Percy⊕ and PBA Oura⊕ (dun) and PBA Noosa⊕ (blue)

Lentil

Nipper⊕, PBA Ace⊕, PBA Blitz⊕, PBA Bolt⊕, PBA Flash⊕, PBA Hallmark XT⊕, PBA Highland XT⊕, PBA Hurricane XT⊕, PBA Jumbo2⊕ and PBA Kelpie XT⊕ (red), and PBA Greenfield⊕ (green)

Table 1 Sowing and harvest time of the different pulse species at Methul, 2021.

Species	Sowing date	Harvest date
Lupin – narrow-leaf	7 May	2 December
Lupin – albus	7 May	23 December
Faba bean	7 May	18 November
Chickpea	7 May	23 December
Field pea	8 June	18 November
Lentil	7 May	18 November

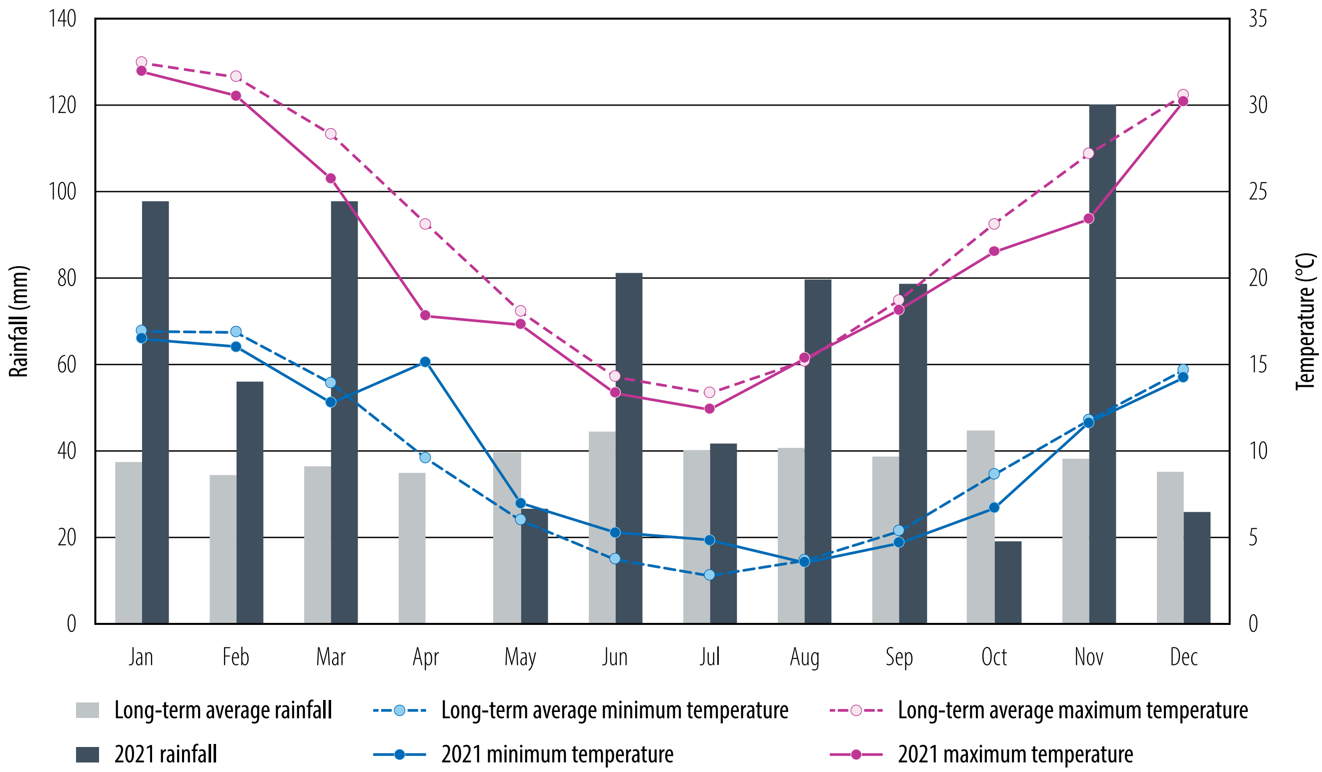

Figure 1 Monthly rainfall and temperature for Anglia, Methul and the associated long-term average.

Results

Seasonal conditions

The 2021 season at Methul was exceptional, with above average rainfall when crops were accumulating biomass and setting pods, and La Niña conditions that resulted in cooler than average temperatures. The site recorded 4 frosts (<0 °C) during the flowering period (August to September). The 2 heaviest frosts included:

1. one moderate frost on 28 August, reaching −1.4 °C and lasting 3 hours below 0 °C
2. one severe frost, on 26 September reaching −1.5 °C and lasting 5 hours below 0 °C.

With adequate soil moisture, long cool spring temperatures, and negligible moisture, temperature or disease stress, the seasonal conditions were conducive to above average grain yields across all pulse species.

Albus lupin

Murringo⁽ᵖ⁾ was the earliest flowering variety (106 days after sowing [DAS]) and had the longest flowering duration (55 days) (Table 2). Rosetta⁽ᵖ⁾ was the last variety to flower (121 DAS) and had the highest hundred seed weight (38.2 g/100 seeds). All varieties had similar grain yields, which ranged from 2.64 t/ha to 2.77 t/ha, with a site mean of 2.70 t/ha.

Table 2 Albus lupin variety evaluation experiment results, Methul 2021.

Variety	Establishment (plants/m²)	Days to flowering (DAS)		Flowering duration (days)	Grain yield (t/ha)	Hundred seed weight (g)
		Start	End			
Luxor	41.8	116.2	161.2	45.0	2.64	35.16
Murringo	42.0	105.7	160.7	55.0	2.77	34.18
Rosetta	44.5	121.0	159.8	38.8	2.71	38.17
Site mean	42.7	114.3	160.6	46.3	2.70	35.84
l.s.d. (*P*>0.05)	n.s.	0.4	0.9	0.8	n.s.	1.23

l.s.d. = least significant difference; n.s. = not significant; DAS = days after sowing.

Faba bean

PBA Nasma⁽ᵖ⁾ was the earliest flowering variety (98 DAS), followed by PBA Nanu⁽ᵖ⁾ (100 DAS) (Table 3). However, they had the shortest flowering duration (43 and 42 days, respectively). PBA Amberley⁽ᵖ⁾ and PBA Samira⁽ᵖ⁾ were last to begin flowering (104 and 103 DAS, respectively), yet flowered for more than 7 days longer than either PBA Nanu⁽ᵖ⁾ or PBA Nasma⁽ᵖ⁾.

Table 3 Faba bean variety evaluation experiment results, Methul 2021.

Variety	Establishment (plants/m²)	Days to flowering (DAS)		Flowering duration (days)	Grain yield (t/ha)	Hundred seed weight (g)
		Start	End			
PBA Amberley	28.0	103.7	155.3	51.7	4.31	65.74
PBA Bendoc	27.9	102.0	155.0	53.0	4.43	58.47
PBA Marne	29.6	101.0	150.3	49.3	4.86	64.25
PBA Nanu	30.4	100.0	142.0	42.0	4.83	63.41
PBA Nasma	24.8	98.0	141.0	43.0	4.87	69.26
PBA Samira	25.5	103.3	154.0	50.7	4.47	70.41
Site mean	28.1	100.9	148.7	47.8	4.66	64.23
l.s.d. (*P*>0.05)	n.s.	1.0	1.8	2.1	0.21	3.45

l.s.d. = least significant difference; n.s. = not significant; DAS = days after sowing.

PBA NasmaΦ (4.87 t/ha), PBA MarneΦ (4.86 t/ha) and PBA NanuΦ (4.83 t/ha) were the highest yielding varieties, significantly higher than all other varieties. PBA AmberleyΦ (4.31 t/ha), PBA SamiraΦ (4.47 t/ha) and PBA BendocΦ (4.43 t/ha) yielded the lowest. PBA SamiraΦ had the highest hundred seed weight (70.4 g/100 seeds), followed by PBA NasmaΦ (69.26 g/100 seeds) and PBA AmberleyΦ (65.7 g/100 seeds), while PBA BendocΦ had the lowest (58.5 g/100 seeds).

Narrow-leaf lupin

There were significant differences in establishment, time of flowering, grain yield and hundred seed weight in the angustifolius experiment (Table 4). PBA JindaleeΦ, which has a vernalisation requirement, was significantly later to flower (120 DAS) and had a significantly shorter flowering duration (40.7 days) than all other varieties. PBA JindaleeΦ was also the lowest yielding (2.39 t/ha). PBA JurienΦ flowered the earliest (105 DAS) and had the longest flowering duration (8 days longer than PBA JindaleeΦ).

PBA BatemanΦ was the highest yielding variety (3.75 t/ha), equivalent to MandelupΦ (3.60 t/ha). In contrast, PBA JindaleeΦ and Wonga were the lowest (2.93 t/ha and 3.13 t/ha respectively). PBA BatemanΦ also had the highest hundred seed weight (17.7 g/100 seeds), and PBA JindaleeΦ the lowest (13.1 g/100 seeds).

Table 4 Narrow-leaf lupin variety evaluation experiment results, Methul 2021.

Variety	Establishment (plants/m^2)	Days to flowering (DAS)		Flowering duration (days)	Grain yield (t/ha)	Hundred seed weight (g)
		Start	End			
Mandelup	45.7	109.0	154.0	45.0	3.60	16.29
PBA Bateman	40.2	108.0	154.7	46.7	3.75	17.72
PBA Gunyidi	41.4	107.3	155.0	47.7	3.45	14.30
PBA Jindalee	36.9	120.3	161.0	40.7	2.93	13.13
PBA Jurien	36.5	105.3	154.0	48.7	3.44	16.97
Wonga	41.6	112.7	158.0	45.3	3.13	14.99
Site mean	40.4	110.4	156.1	45.7	3.38	15.57
l.s.d. (P>0.05)	4.8	1.5	0.4	1.4	0.25	0.68

l.s.d. = least significant difference; DAS = days after sowing.

Chickpea

Genesis™090 and PBA RoyalΦ (kabuli varieties) flowered 5 to 6 days after the 4 desi varieties (Table 5). Flowering duration was not significantly different between all varieties. PBA SlasherΦ was the highest yielding variety (2.16 t/ha), which was significantly higher than all other varieties, followed by Striker (1.95 t/ha). In comparison, PBA RoyalΦ, Genesis™090, PBA BoundaryΦ and CBA CaptainΦ had yields that ranged from 1.58 t/ha to 1.69 t/ha, which were all similar in value. The site mean yield (1.77 t/ha) for this experiment was significantly lower than all other pulse species at this site. This is attributed to the cooler than average mean daily temperatures affecting pod set during the critical reproductive window in September and October.

The kabuli varieties had a significantly higher hundred seed weight (32.1 to 32.7 g/100 seeds) in comparison to the desi varieties, which ranged between 21.2 g/100 seeds and 23.4 g/100 seeds.

Table 5 Chickpea variety evaluation experiment results, Methul 2021.

Variety	Establishment (plants/m^2)	Days to flowering (DAS)	Flowering duration (days)	Grain yield (t/ha)	Hundred seed weight (g)
CBA Captain	36.1	126.0	44.7	1.69	23.11
PBA Boundary	39.2	126.7	44.7	1.59	21.20
PBA Slasher	39.3	126.7	45.3	2.16	22.32
PBA Striker	38.3	126.0	44.3	1.95	23.38
Genesis™090	41.4	131.3	46.3	1.58	32.10
PBA Royal	39.0	133.3	46.7	1.67	32.70
Site mean	38.9	128.3	45.3	1.77	25.80
l.s.d. (*P*>0.05)	n.s.	0.8	n.s.	0.19	1.61

l.s.d. = least significant difference; n.s. = not significant; DAS = days after sowing.

Field pea

PBA Butler$^{\phi}$, PBA Pearl$^{\phi}$, PBA Taylor$^{\phi}$ and PBA Wharton$^{\phi}$ were the highest yielding varieties and, while not significantly different from one another, each had a grain yield over 3.41 t/ha (Table 6). In contrast, PBA Percy$^{\phi}$ and Sturt$^{\phi}$ were the lowest yielding varieties (2.70 and 2.60 t/ha, respectively) (Table 6). PBA Percy$^{\phi}$ was the earliest flowering variety (98 DAS), followed by Sturt$^{\phi}$ (101 DAS). PBA Butler$^{\phi}$ was the last to begin flowering (111 DAS).

PBA Percy$^{\phi}$ had the highest hundred seed weight (21.3 g/100 seeds), whilst Sturt had the lowest (16.8 g/100 seeds).

Table 6 Field pea variety evaluation experiment results, Methul 2021.

Variety	Establishment (plants/m2)	Days to flowering (DAS)		Flowering duration (days)	Grain yield (t/ha)	Hundred seed weight (g)
		Start	End			
PBA Butler	50.5	110.7	135.7	25.0	3.41	19.43
PBA Noosa	47.0	103.7	137.0	33.3	3.26	19.75
PBA Oura	42.9	103.0	137.3	34.3	2.94	20.97
PBA Pearl	38.7	103.7	137.3	33.7	3.48	19.36
PBA Percy	45.3	97.7	138.3	40.7	2.70	21.30
PBA Taylor	48.1	106.7	135.7	29.0	3.57	19.59
PBA Wharton	42.2	107.3	137.0	29.7	3.41	19.43
Sturt	40.6	101.3	137.7	36.3	2.60	16.82
Site mean	44.4	104.3	137.0	32.7	3.17	19.58
l.s.d. (*P*>0.05)	7.1	1.6	n.s.	2.9	0.21	0.68

l.s.d. = least significant difference; n.s. = not significant; DAS = days after sowing.

Lentil

PBA Blitz$^{\phi}$ and PBA Kelpie XT$^{\phi}$ were the earliest flowering varieties (111 and 112 DAS, respectively) (Table 7). However, varieties such as PBA Ace$^{\phi}$, PBA Highland XT$^{\phi}$ and PBA Hurricane XT$^{\phi}$ flowered for a similar duration as PBA Blitz$^{\phi}$ (53 to 54 days) despite flowering 3 to 6 days after PBA Blitz$^{\phi}$. Weather conditions were conducive to flowering and, due to the indeterminate nature of lentils, they continued to flower over a long period of time. There were significant differences in the number of days until the end of flowering with PBA Kelpie XT$^{\phi}$ finishing flowering earliest (159 DAS) and PBA Ace$^{\phi}$, finishing flowering latest (170 DAS).

The highest yielding varieties were PBA Kelpie XT(I) (4.2 t/ha), PBA Jumbo2(I) (4.0 t/ha), PBA Greenfield(I) (4.0 t/ha) and PBA Ace(I) (3.9 t/ha). Nipper(I) was the lowest yielding variety (3.1 t/ha).

Table 7 Lentil variety evaluation experiment results, Methul 2021.

Variety	NDVI+ (18/8/21)	Vigour Score* (18/8/21)	Days to flowering (DAS)		Flower duration (days)	Grain yield (t/ha)
			Start	End		
Nipper	0.49	6.5	130.5	166.0	35.5	3.09
PBA Ace	0.71	9.0	117.0	170.0	53.0	3.85
PBA Blitz	0.60	8.5	110.5	163.0	52.5	3.72
PBA Bolt	0.57	9.0	116.5	167.5	51.0	3.78
PBA Flash	0.57	9.0	123.5	163.0	39.5	3.36
PBA Greenfield	0.60	8.0	124.0	168.0	44.0	3.97
PBA Hallmark XT	0.67	9.0	117.5	167.5	50.0	3.29
PBA Highland XT	0.51	8.5	114.0	167.5	53.5	3.71
PBA Hurricane XT	0.61	9.0	115.0	169.0	54.0	3.75
PBA Jumbo2	0.60	9.0	115.5	169.0	53.5	3.97
PBA Kelpie XT	0.59	9.0	111.5	159.0	47.5	4.19
Site mean	0.60	8.6	118.2	166.6	48.4	3.63
l.s.d. (*P*>0.05)	0.13	1.1	2.7	3.3	3.9	0.38

l.s.d. = least significant difference; +NDVI: normalised difference vegetation index; *Vigour score: 1 = low, 9 = high; DAS = days after sowing.

Summary

The 2021 winter growing season was exceptionally favourable, particularly through the critical reproductive window, with a combination of cool temperatures, minimal frosts and adequate soil moisture resulting in all experiments producing high grain yields (overall site average of 3.2 t/ha). The lentil, chickpea and albus lupin experiments did not show any trends between flowering and yield. The field pea experiment showed a moderately strong trend that indicated yields were higher in varieties that began flowering later and had a shorter flowering duration. The narrow-leaf lupin experiment showed a moderately strong trend that indicated yields were higher in varieties that flowered early. Narrow-leaf lupins also had a moderately strong correlation between higher hundred seed weight and higher grain yield. The faba bean experiment showed a strong correlation between varieties that flowered early and had a shorter flowering duration, and higher yields.

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Pulses

Albus lupin, faba bean, vetch, lentil and chickpea variety experiments – Rankins Springs 2021

Jessica Simpson, Mark Richards, Dr Neroli Graham and Karl Moore

NSW DPI, Wagga Wagga

Key findings

Faba bean

- PBA Amberley⊕ was the highest yielding variety, while PBA Samira⊕, PBA Nanu⊕, PBA Marne⊕, PBA Bendoc⊕ and Nasma⊕ had similar grain yields.
- PBA Marne⊕ and PBA Nasma⊕ had the highest hundred seed weight.
- PBA Nanu⊕ and PBA Nasma⊕ were the earliest to flower and continued to flower for over 50 days. PBA Amberley⊕ and PBA Samira⊕ were last to begin flowering and had two of the three shortest flowering durations.

Albus lupin

- The early flowering Murringo⊕ was the highest yielding variety, while Luxor⊕ and Rosetta⊕ yielded similarly.
- Murringo⊕ was the earliest flowering, followed by Luxor⊕ then Rosetta⊕.
- Rosetta⊕ had the highest hundred seed weight, while Luxor⊕ had the lowest.

Vetch

- Timok⊕ and Volga⊕ were the highest yielding varieties. Studenica⊕ and Morava⊕ yielded the lowest and were not significantly different from each other.
- There were no significant differences in peak dry matter between varieties.
- Studenica⊕ was first to flower and had the longest flowering duration. Morava⊕ flowered last.
- Studenica⊕ was the earliest to mature, followed by Volga⊕, and Timok⊕. Morava⊕ matured significantly later.

Lentil

- The highest yielding variety was PBA Ace⊕. There was some loss of pod/seed due to weather conditions before harvest, but this did not influence grain yield values.
- PBA Blitz⊕ and PBA Kelpie XT⊕ were the earliest flowering varieties and had the longest flowering duration. Nipper⊕ and PBA Flash⊕ flowered last.
- PBA Kelpie XT⊕ and PBA Hallmark XT⊕ matured earliest, while Nipper⊕, PBA Ace⊕ and PBA Jumbo2⊕ matured significantly later.

Chickpea

- Average chickpea grain yield was significantly lower than all other pulse species at this site. This is attributed to the cooler than average mean daily temperatures affecting pod set during the critical reproductive window.
- While all varieties yielded above average for this environment, PBA Slasher⊕ was the best performing variety with a grain yield of 2.8 t/ha.

Keywords Rankins Springs, 2021, pulses, legumes, variety

Introduction

Variety experiments were conducted at Rankins Springs in 2021 to evaluate the phenology and grain yield responses of 6 faba bean, 3 albus lupin, 4 vetch and 11 lentil varieties. Data was collected to assess each variety's establishment (scores), flowering dates, maturity rating, grain yield and seed weight.

In addition, chickpea evaluation experiments were conducted at Rankins Springs in 2017, 2019, 2020 and 2021 to assess a range of commercially available chickpea varieties. The predicted mean yield values are presented.

Site details

Location	Rankins Springs
Soil type	Sandy loam
Soil pH_{Ca}	4.8 (0–5 cm), 4.4 (5–10 cm), 4.7 (10–15 cm), 5.3 (15–20 cm), 5.6 (20–25 cm), 5.9 (25–30 cm)
Previous crop	Wheat
Rainfall	• Fallow (November–March): 203 mm • Fallow long-term average (LTA): 170 mm • In-crop (April–October): 291 mm • In-crop LTA (April–October): 232 mm
Fertiliser	100 kg/ha, mono-ammonium phosphate (MAP) 50% and single super phosphate (SSP) 50% (blend) (nitrogen [N]: 5, phosphorus [P]: 15.4, potassium [K]: 0, sulfur [S]: 6.25)
Sowing date and harvest date	T Table 1 shows sowing and harvest dates for each species.
Site climate	Figure 1 presents the climate data for the site.

Table 1 Sowing and harvest dates for experiments conducted at Rankins Springs, 2021.

Species	Sowing date	Harvest date
Faba bean	18 May 2021	23 November 2021
Vetch	18 May 2021	23 November 2021
Lentil	18 May 2021	1 December 2021
Lupin	19 May 2021	17 December 2021

Treatments

Variety

Faba bean

PBA Amberley$^{\phi}$, PBA Bendoc$^{\phi}$, PBA Marne$^{\phi}$, PBA Nanu$^{\phi}$, PBA Nasma$^{\phi}$ and PBA Samira$^{\phi}$

Albus lupin

Luxor$^{\phi}$, Murringo$^{\phi}$, and Rosetta$^{\phi}$

Vetch

Morava$^{\phi}$, Studenica$^{\phi}$, Timok$^{\phi}$ and Volga$^{\phi}$

Pulses

Lentil

NipperⒹ, PBA AceⒹ, PBA BlitzⒹ, PBA BoltⒹ, PBA FlashⒹ, PBA Hallmark XTⒹ, PBA Highland XTⒹ, PBA Hurricane XTⒹ, PBA Jumbo2Ⓓ and PBA Kelpie XTⒹ (red), and PBA GreenfieldⒹ (green)

Chickpea

Year 2017: NeelamⒹ, PBA BoundaryⒹ, PBA SlasherⒹ and PBA StrikerⒹ

Year 2019: CBA CaptainⒹ, Genesis™090, NeelamⒹ, PBA BoundaryⒹ, PBA HatTrickⒹ, PBA MaidenⒹ, PBA SeamerⒹ, PBA SlasherⒹ and PBA StrikerⒹ

Year 2020: CBA CaptainⒹ, NeelamⒹ, PBA MaidenⒹ, PBA SlasherⒹ and PBA StrikerⒹ

Year 2021: CBA CaptainⒹ, NeelamⒹ, PBA MaidenⒹ, PBA SlasherⒹ and PBA StrikerⒹ

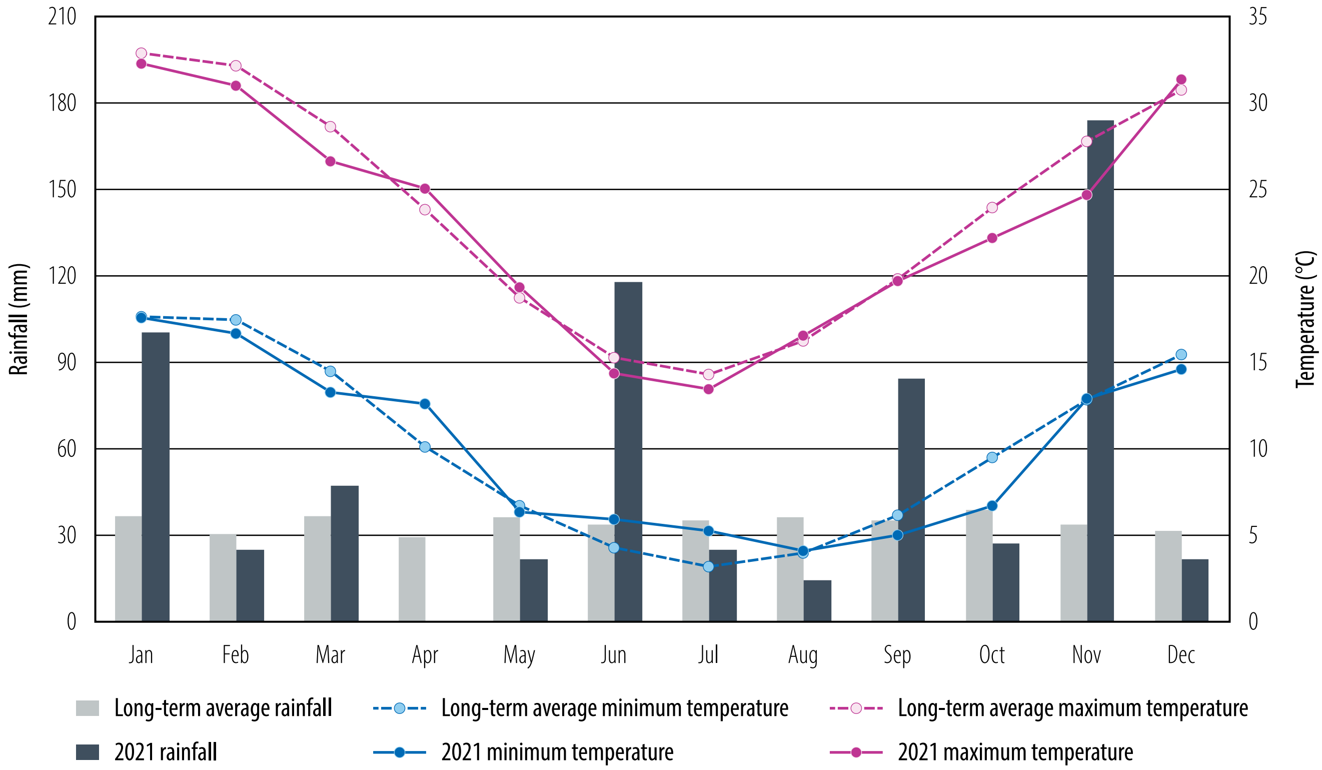

Figure 1 Monthly rainfall and monthly average minimum and maximum temperature for Hillview, Rankins Springs in 2021 and the long-term average.

Results

Seasonal conditions

The 2021 season at Rankins Springs was exceptional with above average rainfall in June, September and November. La Niña conditions resulted in cooler than average temperatures and wetter conditions throughout the growing season. The Rankins Springs site recorded 5 frosts (<0 °C) during flowering (August to September). There was a severe frost of –2 °C on 26 September that lasted 4 hours. Overall, the seasonal conditions were conducive to above average grain yields across all pulse species with a long, cool spring combined with negligible moisture, heat or disease stress.

Faba bean

PBA AmberleyⒹ had the highest yield (3.9 t/ha), while PBA SamiraⒹ, PBA NanuⒹ, PBA MarneⒹ, PBA BendocⒹ and NasmaⒹ had similar yields ranging from 3.18 t/ha to 3.43 t/ha (Table 2).

PBA NanuⒹ and PBA NasmaⒹ were the earliest flowering varieties (87 days after sowing [DAS]) and had some of the longest flowering durations, with 51 and 50.7 days, respectively. PBA AmberleyⒹ and PBA SamiraⒹ were last to begin flowering (96 DAS) and had two of the three shortest flowering durations.

Table 2 Faba bean variety evaluation experiment results, Rankins Springs 2021.

Variety	Establishment (plants/m²)	Flowering (DAS)		Flowering duration (days)	Grain yield (t/ha)	Hundred seed weight (g)
		Start	End			
PBA Amberley	27.7	96.7	144.0	47.3	3.89	62.2
PBA Bendoc	35.0	93.3	146.3	53.0	3.29	57.8
PBA Marne	32.3	91.3	138.0	46.7	3.32	76.4
PBA Nanu	35.7	87.0	138.0	51.0	3.39	67.3
PBA Nasma	30.7	87.0	137.7	50.7	3.18	82.3
PBA Samira	34.0	96.0	145.7	49.7	3.43	67.6
Site mean	32.3	91.1	140.8	49.7	3.41	69.2
l.s.d. (*P*<0.05)	n.s.	1.7	2.9	3.3	0.25	3.9

l.s.d. = least significant difference; n.s. = not significant, DAS = days after sowing.

Albus lupin

There were significant differences in time to flowering, grain yield and hundred seed weight in the albus lupin experiment (Table 3). Murringo⁽ᵈ⁾ was the earliest flowering variety (94.5 DAS), with Luxor⁽ᵈ⁾ and Rosetta⁽ᵈ⁾ flowering later (100 and 108 DAS, respectively). The early flowering Murringo⁽ᵈ⁾ was the highest yielding variety (3.7 t/ha), while Luxor⁽ᵈ⁾ and Rosetta⁽ᵈ⁾ yielded 3.4 t/ha, similar to the site mean at 3.5 t/ha. Rosetta⁽ᵈ⁾ had the highest hundred seed weight (34.5 g), while Luxor⁽ᵈ⁾ had the lowest at 31.8 g.

Table 3 Lupin variety evaluation experiment results, Rankins Springs 2021.

Variety	Establishment (plants/m²)	Vigour score*	Flowering (DAS)		Flowering duration (days)	Grain yield (t/ha)	Hundred seed weight (g)
			Start	End			
Luxor	41.3	6.5	100.3	151.7	51.3	3.42	31.76
Murringo	43.3	7.7	94.5	146.8	52.3	3.69	33.16
Rosetta	46.8	7.5	108.3	148.8	40.5	3.38	34.53
Site mean	43.8	7.2	101.1	149.1	48.1	3.50	33.15
l.s.d. (*P*<0.05)	n.s.	0.9	0.8	1.2	1.2	0.19	1.07

l.s.d. = least significant difference; n.s. = not significant; *Vigour score: 1 = poor, 9 = excellent.

Vetch

Timok⁽ᵈ⁾ (3.82 t/ha) and Volga⁽ᵈ⁾ (3.67 t/ha) yielded significantly more than Studenica⁽ᵈ⁾ or Morava⁽ᵈ⁾, both 3.22 t/ha (Table 4). Studenica⁽ᵈ⁾ was first variety to flower (98 DAS) and had the longest flowering duration, Morava⁽ᵈ⁾ was the last to start flowering (122 DAS). Morava⁽ᵈ⁾ was the last variety to finish flowering (151 DAS), nearly 2 weeks after the other 3 varieties had finished (approximately 138 DAS), around 4 October 2021. This was reflected in the visual maturity score where Studenica⁽ᵈ⁾ started to mature before Timok⁽ᵈ⁾ and Volga⁽ᵈ⁾, with Morava⁽ᵈ⁾ having only started to mature at the time that the score was taken.

There were also significant differences in maturity. Studenica⁽ᵈ⁾ was the earliest maturing variety, followed by Volga⁽ᵈ⁾ and Timok⁽ᵈ⁾. Morava⁽ᵈ⁾ was significantly later maturing.

Pulses

Table 4 Vetch variety evaluation experiment results, Rankins Springs 2021.

Variety	Flowering (DAS)		Flowering duration (days)	Dry matter (t/ha) 27 Sep 2021	Maturity score** 18 Nov 2021	Grain yield (t/ha)
	Start	End				
Timok	110.7	138.0	27.3	6.24	4.3	3.82
Volga	109.3	137.7	28.3	5.25	3.3	3.67
Studenica	98.0	137.3	39.3	5.92	1.0	3.22
Morava	121.7	151.3	29.7	5.75	8.7	3.22
Site mean	109.9	141.1	31.2	5.79	4.3	3.48
l.s.d. (P<0.05)	1.8	1.4	1.8	n.s.	1.6	0.46

l.s.d. = least significant difference; n.s. = not significant; **Maturity score: 1 = early, 9 = late.

Lentil

The highest yielding variety was PBA Ace^(PBR) (4.01 t/ha), while the lowest yielding were PBA Flash^(PBR) and Nipper^(PBR) (2.85 and 2.91 t/ha, respectively) (Table 5). The site mean for grain yield was 3.26 t/ha. There was some loss of pod/seed due to weather conditions before harvest, which would have slightly affected grain yield values.

PBA Blitz^(PBR) and PBA Kelpie XT^(PBR) were the earliest flowering varieties (98.5 and 101 DAS, respectively) and had the longest flowering duration (61.5 and 65 days, respectively). In contrast, Nipper^(PBR) and PBA Flash^(PBR) flowered the latest (114 and 112 DAS, respectively) and had the 2 shortest flowering durations (47 and 47.5 days, respectively).

There were significant differences in maturity with PBA Kelpie XT^(PBR) and PBA Hallmark XT^(PBR) maturing early, while Nipper^(PBR), PBA Ace^(PBR) and PBA Jumbo2^(PBR) matured last.

Table 5 Lentil variety evaluation experiment results, Rankins Springs 2021.

Variety	Vigour score*	Days to flower (DAS)	Flower duration (days)	Maturity score**	Grain yield (t/ha)
Nipper	7.0	114.0	47.0	6.0	2.91
PBA Ace	8.0	108.0	53.5	6.0	4.01
PBA Blitz	8.5	98.5	61.5	5.0	3.19
PBA Bolt	8.5	103.5	59.5	4.0	3.40
PBA Flash	8.0	112.0	47.5	5.0	2.85
PBA Greenfield	7.5	108.0	52.5	5.0	3.58
PBA Hallmark XT	8.0	105.5	57.5	3.0	3.33
PBA Highland XT	8.5	102.0	61.0	4.0	3.28
PBA Hurricane XT	7.5	108.0	56.0	4.0	3.49
PBA Jumbo2	8.0	106.0	56.0	6.0	3.19
PBA Kelpie XT	8.5	101.0	65.0	3.0	3.25
Site mean	8.0	105.6	56.4	4.8	3.26
l.s.d. (P<0.05)	n.s.	2.5	4.0	2.0	0.71

l.s.d. = least significant difference; n.s. = not significant; *Vigour score: 1 = poor, 9 = excellent; **Maturity score: 1 = early, 9 = late.

Chickpea

The 2021 season produced high grain yields across all varieties at Rankins Springs with a site mean of 2.60 t/ha (Table 6). The best performing variety was PBA Slasher^(PBR) yielding 108% (2.82 t/ha) of site predicted mean yield. CBA Captain^(PBR) had the lowest yield in 2021 (2.44 t/ha) which was 94% of the site predicted mean yield.

Grain yield analysis for commercial varieties over the 2017 to 2021 growing seasons showed variation, with 2017 having the lowest grain yield with a site mean of 1.16 t/ha. On average, varieties yielded more than 1.44 t/ha lower compared with 2021. Three varieties (Neelam$^{\phi}$, PBA Slasher$^{\phi}$ and PBA Striker$^{\phi}$) were included in all 4 experimental years. In 2017, the highest yielding varieties were PBA Boundary$^{\phi}$ and PBA Slasher$^{\phi}$ (both 1.29 t/ha).

Chickpea evaluation experiments conducted at Rankins Springs across 4 years highlight the exceptional 2021 season with high yields for all varieties and a site mean of 2.60 t/ha. In comparison, the less favourable 2017 and 2019 seasons produced site mean yields of 1.16 t/ha and 1.38 t/ha, respectively.

Table 6 Grain yield (t/ha) of chickpea variety experiments conducted at Rankin Springs from 2017 to 2021.

Variety	Grain yield (t/ha) (%SMY)			
	Experiment year			
	2017	2019	2020	2021
CBA Captain	*	1.38 (100)	2.59 (109)	2.44 (94)
Genesis090	*	1.41 (102)	*	*
Neelam	1.27 (109)	1.47 (107)	2.68 (113)	2.67 (102)
PBA Boundary	1.29 (111)	1.36 (99)	*	*
PBA HatTrick	*	1.36 (98)	*	*
PBA Maiden	*	1.28 (93)	2.61 (110)	2.59 (99)
PBA Seamer	*	1.29 (93)	*	*
PBA Slasher	1.29 (111)	1.48 (107)	2.74 (115)	2.82 (108)
PBA Striker	1.27 (109)	1.50 (108)	2.66 (112)	2.74 (105)
Site mean	1.16 (100)	1.38 (100)	2.37 (100)	2.60 (100)
Sowing date	17 May	9 May	18 May	19 May
Harvest date	12 Dec	22 Nov	10 Dec	14 Dec

%SMY = Percentage of grain yield compared with site mean yield; * = variety not included in experiments that year.

Summary

The combination of mild winter temperatures, minimal frosts and adequate soil moisture during spring and early summer resulted in all pulse and legume species producing high yields when compared with previous years. Due to minimal biotic and abiotic stress during the growing season, there was no relationship between flowering dates and yield for any of the species tested, however, there were significant differences in the yields between varieties within individual species.

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Lupin phenology and yield responses to sowing date and water treatment – Wagga Wagga and Rankins Springs 2021

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Key findings

- Mandelup⁽ᵈ⁾ and PBA Bateman⁽ᵈ⁾ were the fastest maturing varieties at Wagga Wagga.
- Early sowing at both sites and water treatment (Wagga Wagga) prolonged the growth duration.
- At Wagga Wagga, sowing date had no effect on biomass accumulation, however, more biomass was accumulated in the water treatment.
- Early sowing increased biomass at Rankins Springs.
- PBA Jurien⁽ᵈ⁾ showed a high and stable grain yield over the 2 locations in 2021. At Wagga Wagga, it was the highest yielding variety, while at Rankins Springs only PBA Bateman⁽ᵈ⁾ yielded higher.
- PBA Jurien⁽ᵈ⁾ and PBA Bateman⁽ᵈ⁾ had the highest seed weight at Wagga Wagga, while Mandelup⁽ᵈ⁾ and PBA Bateman⁽ᵈ⁾ had the highest seed weight at Rankins Springs.
- Machine grain yield increased with irrigation and late sowing.

Keywords lupin, phenology, sowing date, water, Wagga Wagga, Rankins Springs, yield, southern

Introduction

In southern NSW, abiotic stresses such as heat and moisture stress late in the season and frost damage during the season limit lupin yield potential. To maximise yield, it is important to optimise sowing time to ensure that critical growth phases do not coincide with the high risks of abiotic stress. This paper presents results from the Wagga Wagga and Rankins Springs sites (southern NSW) in 2021 and discusses the influence of water treatment (WT) and/or sowing date (SD) on lupin phenology and grain yield responses.

Site details

Site details for Wagga Wagga and Rankins Springs in 2021 are detailed in Table 1.

Table 1 Summary of site conditions and experiment management.

Site	Wagga Wagga, NSW	Rankins Springs, NSW
Location	Wagga Wagga Agricultural Institute (WWAI)	Hillview, Pulletop Paddock
Soil type	Red kandosol	Sandy clay loam
Previous crop	Wheat	Wheat in 2020, canola in 2019
Rainfall	Fallow (November–March): 306 mm Fallow long-term average (LTA): 157 mm In-crop (April–October): 204 mm In-crop LTA: 329 mm	Fallow (November–March): 203 mm Fallow long-term average (LTA): 170 mm In-crop (April–October): 291 mm In-crop LTA: 232 mm
Water treatment	An additional 90 mm was applied periodically during the season for the irrigated treatment as follows: • 13 mm on 11 August • 9.9 mm on 23 August • 15.2 mm on 27 August • 8.7 mm on 9 September • 8.9 mm on 20 September • 4.5 mm on 21 September • 15.3 mm on 7 October • 14.5 mm on 28 October	An additional 6 mm was applied pre-emergent
Starter fertiliser	50% mono-ammonium phosphate (MAP), 50% single super phosphate (SSP) (nitrogen [N]: 5, phosphorus [P]: 15.4, potassium [K]: 0, sulfur [S]: 6.25) blend- Wengfu Australia	Utiliser pulse mix 120 kg/ha (N: 7.48; P: 17.64; K: 6.24; calcium [Ca]: 6.4; zinc [Zn]: 0.32; manganese [Mn]: 3.2)
Target plant density	40 plants/m^2	40 plants/m^2
Weed management	• Knockdown (24 February): BS1000® Bio-degradable (adjuvant) 60 mL/100mL + Spraytop® 250 SL (herbicide; mode of action (MOA) group 22) 2.4 L/ha • Pre-emergence (8 April, at sowing): Expedient® (adjuvant) 500 mL/ha + Panzer 450 (herbicide; MOA group 9) 2 L/ha + Striker® (herbicide; MOA group 14) 100 mL/ha + Simagen 900 WG (herbicide; MOA group 5) 2.1 kg/ha	• Pre-emergence (at sowing): Simazine 900 WG (herbicide, MOA group 5) 1.4 kg/ha on 27 April • SD1: Treflan™ (herbicide, MOA group 3) 1.2 L/ha on 26 April • SD2: Treflan™ (herbicide, MOA group 3) 1.2 L/ha on 19 May • SD2: Panzer 450 (herbicide; MOA group 9) 2 L/ha on 19 May
Disease management	• Dithane™ Rainshield™ NeoTec™ (fungicide; MOA group M3) 1 kg/ha on 23 June • Veritas® Opti (fungicide; MOA groups 3 and 11) 500 mL/ha on 23 June • Veritas® Opti (fungicide; MOA groups 3 and 11) 500 mL/ha on 21 July • Dithane™ Rainshield™ NeoTec™ (fungicide; MOA group M3) 1 kg/ha on 20 August	Nil
Pest management	• Trojan® (insecticide, MOA group 3A) 8 mL/ha on 21 June • Karate Zeon® (insecticide, MOA group 3A) 36 mL/ha on 22 October • Karate Zeon® (insecticide, MOA group 3A) 36 mL/ha on 11 November	• Mouse off at label rate on 26 April • Mouse off at label rate on 3 May • Astral® 250 EC (insecticide, MOA group 3A) 50mL/ha on 27 August • Karate Zeon® (insecticide, MOA group 3A) 36 mL/ha on 22 October
Desiccation	• Reglone® Non-Residual (herbicide, MOA group 22) 1.2 L/ha on 14 December • Spraytop® 250 SL (herbicide, MOA group 22) 0.8 L/ha on 14 December	Nil

Treatments

Table 2 Summary of the experiment treatments; variety, sowing date, and water treatment at Wagga Wagga and Rankins Springs, 2021.

Site	Wagga Wagga, NSW	Rankins Springs, NSW
Variety	PBA Jurien⁽ᵇ⁾, Mandelup⁽ᵇ⁾, PBA Bateman⁽ᵇ⁾ and Wonga⁽ᵇ⁾	PBA Jurien⁽ᵇ⁾, Mandelup⁽ᵇ⁾, PBA Bateman⁽ᵇ⁾, Wonga⁽ᵇ⁾, PBA Jindalee⁽ᵇ⁾ and PBA Gunyidi⁽ᵇ⁾
Sowing date	SD1: 29 April	SD1: 26 April
	SD2: 21 May	SD2: 19 May
Water treatment	Dryland and irrigated	Dryland only

Results

Seasonal conditions

Overall, in 2021 southern NSW had an atypical rainfall pattern, which included very late season rainfall, in October and November. This delayed crop maturity and slowed crop dry down. As a result, crops were desiccated to allow for machine harvesting.

Mouse damage, at Wagga Wagga, was higher in the later sowing date (SD2) when compared with the earlier sowing date (SD1) across all varieties.

Wagga Wagga

Phasic development

Generally, the growing season was longer in the early sown experiment (SD1) with the time to plant maturity being similar for the 2 sowing dates (Figure 1). The greatest difference was the increased time that early sown crops spent in the vegetative and pod filling phases (Figure 1).

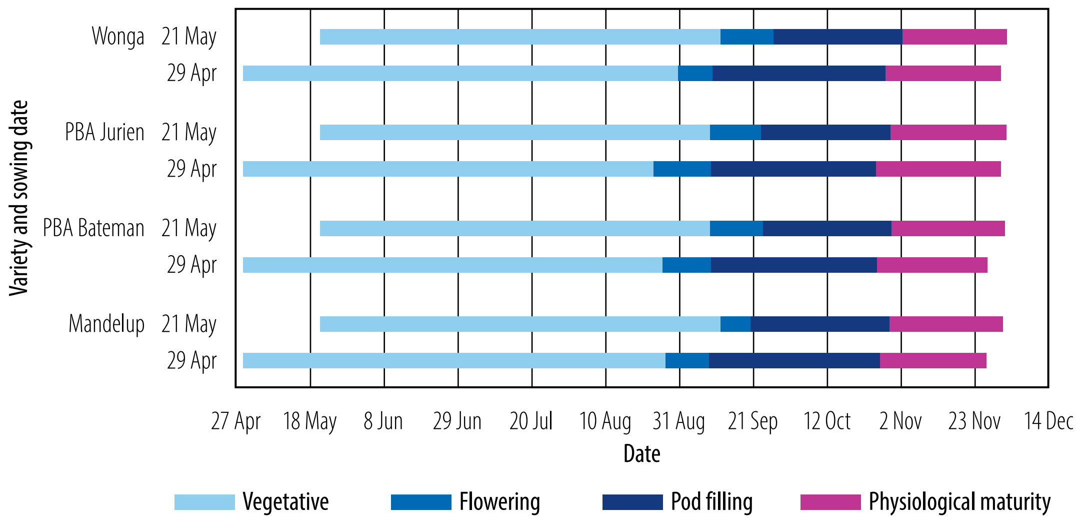

Figure 1 Duration and/or transition between growth phases of 4 lupin varieties, Wagga Wagga 2021.

Delaying sowing from late April (SD1: 29 April) to late May (SD2: 21 May) increased the time to establishment from 9.3 to 10.9 days respectively, due to the colder soil temperatures (Table 3). PBA Jurien⁽ᵇ⁾ and Mandelup⁽ᵇ⁾ had the lowest plant densities both below 40 plants/m^2. Variety × sowing date affected phenological traits (time to flowering and podding) (Table 3). This indicates common genetic control for these traits. Late sowing (SD2) accelerated phenological development with less time spent in the vegetative, flowering and pod filling development phases. PBA Jurien⁽ᵇ⁾ and PBA Bateman⁽ᵇ⁾ were the fastest to flowering (50%) at 113.9 days and 115.1 days after sowing, respectively, though Mandelup⁽ᵇ⁾ was the first to achieve 50% of plants containing a pod. Mandelup⁽ᵇ⁾ and PBA Bateman⁽ᵇ⁾ matured earliest, finishing approximately 203 days after sowing (Figure 1).

Table 3 Phenological response to sowing date and water treatment of 4 lupin varieties at Wagga Wagga, 2021.
DTEst = days to establishment; DT50F = days to 50% flowering; DT50P= days to 50% podding; DTPM = days to physiological maturity; Dry = dryland treatment, Wet = water treatment.

Variety	SD	DTEst		DT50F		DT50P		DTPM	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Mandelup	1	9.9	10.7	120.0	120.2	133.0	132.3	208.0	214.7
	2	11.6	10.9	114.0	114.0	122.7	122.0	192.0	196.0
PBA Bateman	1	8.7	8.2	119.5	119.5	133.8	133.1	208.5	214.7
	2	10.0	9.9	111.0	111.0	126.3	125.3	193.5	196.0
PBA Jurien	1	10.0	9.2	116.5	116.7	133.0	133.0	214.0	217.0
	2	11.7	10.8	111.0	111.0	124.4	126.3	194.2	196.0
Wonga	1	9.5	8.7	123.5	123.7	134.5	132.9	214.0	217.0
	2	11.1	11.0	114.0	114.0	129.0	129.0	194.2	196.0
Variety	l.s.d.	n.s.		0.5		2.3		0.6	
SD	l.s.d.	1.4		0.6		1.7		0.5	
WT	l.s.d.	n.s.		n.s.		n.s.		0.7	
Variety × SD	l.s.d.	n.s.		0.8		3.3		0.9	
Variety × WT	l.s.d.	n.s.		n.s.		n.s.		0.9	
SD × WT	l.s.d.	n.s.		n.s.		n.s.		n.s.	
Variety × SD × WT	l.s.d.	n.s.		n.s.		n.s.		n.s.	

l.s.d = least significant difference = l.s.d. ($P<0.05$); n.s. = not significant.

Pulses

Grain yield

Differences in grain yield were observed due to variety, water treatment × sowing date and sowing date × variety (Table 4).

- Under ideal spring conditions in 2021, where the soil moisture was not significantly limiting, and temperatures were optimal, there was no loss in grain yield from delayed sowing or additional water treatments.
- PBA Jurien⁽ᵈ⁾ had the highest grain yield of the 4 varieties with 3.07 t/ha; Wonga⁽ᵈ⁾ had the lowest with 2.64 t/ha.
- There were contrasting effects on grain yield when sowing was delayed, and supplementary water was added.
  - When no supplementary water was applied sowing earlier had a 5% yield advantage over the later sowing date, with 2.82 t/ha for SD1 compared with 2.68 t/ha for SD2.
  - When supplementary water was applied sowing earlier resulted in a 13% or 0.4 t/ha yield reduction compared to the later sowing date, with 2.74 t/ha for SD1 and 3.15 t/ha for SD2.
- Varieties behaved differently in response to sowing date.
  - Mandelup⁽ᵈ⁾ and Wonga⁽ᵈ⁾ achieved their largest grain yields when sown later (SD2) with 2.95 t/ha and 2.94 t/ha, respectively. Sowing earlier reduced grain yields by 11% and 20% respectively for Mandelup⁽ᵈ⁾ and Wonga⁽ᵈ⁾.
  - In contrast, PBA Bateman⁽ᵈ⁾ and PBA Jurien⁽ᵈ⁾ had higher grain yields when sown earlier (SD1) with 3.01 and 3.15 t/ha, respectively. Delaying sowing reduced yield by 8% and 5%, respectively for PBA Bateman⁽ᵈ⁾ and PBA Jurien⁽ᵈ⁾.

Biomass accumulation

Sowing date had a small but significant effect on biomass accumulation, with 10 t/ha accumulated for SD1 and 9.3 t/ha for SD2. Adding supplementary water, increased biomass to 10.7 t/ha well above the 8.7 t/ha achieved in the dryland treatments. As with grain yield, there were differences in the amount of biomass the varieties accumulated for the 2 sowing dates. Mandelup$^{\phi}$ and Wonga$^{\phi}$ accumulated more biomass when sown later (SD2) while PBA Bateman$^{\phi}$ and PBA Jurien$^{\phi}$ accumulated more when sown earlier (SD1).

Seed weight

PBA Jurien$^{\phi}$ and PBA Bateman$^{\phi}$ had the highest hundred seed weight with 14.0 g/100 seeds, which was significantly greater than 12.4 g/100 seeds for Wonga$^{\phi}$. Supplementary water decreased the hundred seed weight from 13.6 to 13.2 g/100 seeds.

Harvest index

Variety, sowing date and water treatment affected harvest index (Table 4). Harvest index was lowest for Wonga$^{\phi}$ at 28% and highest for PBA Jurien$^{\phi}$ at 32%. Early sowing and supplementary water decreased the harvest index, due to relatively higher biomass accumulated, whilst grain yield was not similarly affected.

Table 4 Biomass and grain yield response to sowing date and water treatment of 4 lupin varieties at Wagga Wagga, 2021. *Dry = dryland treatment, Wet = irrigated treatment.*

Variety	SD	Biomass (t/ha)		Hundred seed weight (g)		Grain yield (t/ha)		Harvest Index	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Mandelup	1	8.89	9.36	13.4	12.8	2.72	2.51	0.30	0.27
	2	7.32	11.09	12.8	13.1	2.51	3.39	0.34	0.31
PBA Bateman	1	10.42	11.84	14.7	13.5	3.13	2.88	0.30	0.24
	2	8.15	9.93	14.1	13.8	2.73	2.82	0.34	0.29
PBA Jurien	1	9.45	11.21	14.4	13.5	3.13	3.17	0.33	0.30
	2	7.60	10.95	14.1	14.1	2.62	3.37	0.34	0.31
Wonga	1	9.08	10.01	12.4	11.8	2.29	2.38	0.25	0.24
	2	8.40	11.05	13.0	12.6	2.88	3.01	0.34	0.28
Variety	l.s.d	n.s.		0.33		0.31		0.01	
SD	l.s.d	0.62		n.s.		n.s.		0.01	
WT	l.s.d	0.81		0.50		n.s.		0.01	
Variety × SD	l.s.d	0.98		n.s..		0.43		0.02	
Variety × WT	l.s.d	n.s.		n.s.		n.s.		n.s.	
SD × WT	l.s.d	0.94		0.37		0.35		n.s.	
Variety× SD × WT	l.s.d	n.s.		n.s.		n.s.		n.s.	

l.s.d = least significant difference = l.s.d ($P<0.05$); n.s. = not significant.

Rankins Springs

The 6 varieties responded differently to the 2 sowing dates (SD1: 26 April and SD2: 19 May) at Rankins Springs. Early sowing (SD1) prolonged the crop duration to 190 days, for the time between sowing and physiological maturity, when compared with 172 days for SD2. Plant density differed between the varieties with PBA Gunyidi$^{\phi}$ having the highest establishment of 46.2 plants/m^2 and PBA Jurien$^{\phi}$ the lowest with 36.7 plants/m^2.

Seed weight

Seed weight responded to the variety × sowing date interaction (Table 5). Mandelup$^{\phi}$ and PBA Bateman$^{\phi}$ had the highest hundred seed weight, over 18 g/100 seeds and PBA Jindalee$^{\phi}$ the lowest at only 13.81 g/100 seeds. Hundred seed weight was higher for SD1 (17.8 g/100 seeds) than for SD2 (15.1 g/100 seeds).

Grain yield

Grain yield differed between varieties (Table 5). PBA Bateman$^{\phi}$ (4.72 t/ha) yielded significantly higher than all the other varieties tested. Grain yield of PBA Jurien$^{\phi}$, Mandelup$^{\phi}$ and PBA Gunyidi$^{\phi}$ was not as high as PBA Bateman$^{\phi}$, but all achieved a yield over 4 t/ha.

Biomass

Only sowing date affected biomass (Table 5) with early sowing (SD1) increasing the amount of accumulated biomass by 1.2 t/ha over the later sown (SD2) amount of 10.42 t/ha.

Harvest index

Both variety and sowing date influenced harvest index. Mandelup$^{\phi}$, PBA Bateman$^{\phi}$ and PBA Gunyidi$^{\phi}$ all had a harvest index over 0.40 (or 40%). Wonga$^{\phi}$ had the lowest harvest index at only 33%. Late sowing (SD2) improved harvest index compared with early sowing (SD1), 41% to 37%, respectively. This was due to the higher biomass accumulated when sown early with no difference in grain yield between the 2 sowing dates.

Table 5 Biomass and grain yield response to sowing date and water treatment of 6 lupin varieties at Rankins Springs, 2021.

Variety	Sowing date	Crop duration (days)	Harvest biomass (t/ha)	Harvest Index	Grain yield (t/ha)	Plant height (m)	Hundred seed weight (g)	Plant density (plants/m²)
Mandelup	1	193	11.34	0.38	4.19	0.74	19.87	40.2
	2	170	10.24	0.43	4.35	0.74	16.17	39.4
PBA Bateman	1	188	11.87	0.42	4.86	0.77	19.48	37.7
	2	171	10.06	0.46	4.58	0.69	16.65	40.0
PBA Gunyidi	1	187	11.93	0.34	4.03	0.76	17.49	45.7
	2	172	9.70	0.45	4.31	0.68	14.77	46.8
PBA Jindalee	1	195	10.83	0.37	3.98	0.93	14.48	38.8
	2	176	10.41	0.38	3.95	0.78	13.14	35.5
PBA Jurien	1	190	12.04	0.39	4.56	0.79	18.83	36.6
	2	172	11.11	0.39	4.34	0.73	15.63	36.8
Wonga	1	190	11.73	0.31	3.65	0.78	16.50	37.7
	2	172	11.00	0.34	3.76	0.71	13.95	36.3
Variety	l.s.d	n.s.	n.s.	0.05	0.28	0.04	0.54	5.4
SD	l.s.d	n.s.	0.56	0.03	n.s.	0.04	0.41	n.s.
Variety × SD	l.s.d	n.s.	n.s.	n.s.	n.s.	0.05	0.75	n.s.

l.s.d = least significant difference = l.s.d (P<0.05); n.s. = not significant.

Summary

Seasonal conditions significantly influenced phenology, grain yield and quality responses to sowing date, variety and/or water treatment in 2021. However, late sowing shortened growing season duration at both sites. Mild temperatures combined with unlimited soil moisture throughout the growing season masked potential differences in applied management practices, though genotypic differences were evident. For example, both sowing date and water treatment had no effect on grain yield at Wagga Wagga in 2021.

The early flowering PBA Jurien$^{\phi}$ was one of the highest yielding varieties at both locations. PBA Jurien$^{\phi}$ and PBA Bateman$^{\phi}$ had the highest hundred seed weight at Wagga Wagga, while at Rankins Springs Mandelup$^{\phi}$ and PBA Bateman$^{\phi}$ had the highest hundred seed weight.

Pulses

Acknowledgements

This experiment was part of the 'Matching adapted pulse genotypes with soil and climate to maximise yield and profit, with manageable risk in Australian cropping systems' project, BLG118, 2020–22, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

We sincerely thank the Eckermann family, Hillside, Rankins Springs for hosting the experiment site.

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Faba bean phenology and yield responses to sowing date and water treatment – Wagga Wagga 2021

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Key findings

- Early sowing and water treatment increased grain yield.
- PBA Marne⁽ᵖ⁾ and PBA Nasma⁽ᵖ⁾ were the highest yielding varieties, while PBA Amberley⁽ᵖ⁾ and PBA Samira⁽ᵖ⁾ were the lowest yielding.
- PBA Nasma⁽ᵖ⁾ was the earliest maturing variety.
- Early sowing and water treatment prolonged the growth duration.
- More biomass was accumulated in early sowing and under the water treatment.

Pulses

Keywords faba bean, phenology, sowing date, water, Wagga Wagga, yield, southern

Introduction

In southern NSW, abiotic stresses such as heat and moisture stress late in the season combined with cold temperatures and frost damage early in the season can limit faba bean yield potential. To maximise yield, it is important to optimise sowing and water treatment timing to ensure that critical growth phases do not coincide with the high risks from abiotic stress. This paper presents results from the Wagga Wagga site (southern NSW) in 2021 and discusses the influence of water treatment (WT) and/or sowing date (SD) on faba bean phenology and grain yield response.

Site details

Location	Wagga Wagga, NSW
Soil type	Red kandosol
Previous crop	Wheat
Sowing	Target plant density: 25 plants/m^2
Soil pH_{Ca}	6.4 (0–10 cm); 4.9 (10–20 cm)
Fertiliser	100 kg/ha, 50% mono-ammonium phosphate (MAP) and 50% single super phosphate (SSP) (nitrogen [N]:5, phosphorus [P]:15.4, potassium [K]:0, sulfur [S]:6.25) blend
Weed control	Knockdown (8 April 2021): Expedient® (adjuvant) 500 mL/100 L + Panzer 450 (herbicide; mode of action (MOA) group 9) 2 L/ha + Striker® (herbicide; MOA group 14) 100 mL/ha Pre-emergent SD1 (29 April 2021): Simagen 900 WG (herbicide; MOA group 5) 1.4 kg/ha + TriflurX® (herbicide; MOA group 3) 1.2 L/ha Pre-emergent SD2 (23 May 2021): Panzer 450 (herbicide; MOA group 9) 2 L/ha + Simagen 900 WG (herbicide; MOA group 5) 1.4 kg/ha + TriflurX® (herbicide; MOA group 3) 1.2 L/ha

Disease management

- Dithane™ Rainshield™ NeoTec™ (fungicide; MOA group M3) 1 kg/ha (23 June 2021)
- Veritas® Opti (fungicide; MOA groups 3 and 11) 500 mL/ha (23 June 2021)
- Veritas® Opti (fungicide; MOA groups 3 and 11) 500 mL/ha (21 July 2021)
- Dithane™ Rainshield™ NeoTec™ (fungicide; MOA group M3) 2 kg/ha (20 August 2021)

Pest management

- Trojan® (insecticide; MOA group 3A) 8 mL/ha (21 June 2021)
- Karate Zeon®(insecticide; MOA group 3A) 36 mL/ha (22 October 2021)
- Karate Zeon® (insecticide; MOA group 3A) 36 mL/ha (11 November 2021)

Desiccation

- Reglone® Non-residual (herbicide; MOA group 22) 1.2 L/ha (14 December 2021)
- Spraytop® 250 SL (herbicide; MOA group 22) 0.8 L/ha (14 December 2021)

In-crop rainfall (April–October)

204 mm

Harvest date

SD1: 3 December 2021
SD2: 14 December 2021

Treatments

Variety

PBA Amberley$^{\phi}$, PBA Marne$^{\phi}$, PBA Nasma$^{\phi}$ and PBA Samira$^{\phi}$

Sowing date (SD)

SD1: 29 April 2021

SD2: 21 May 2021

Water treatment (overhead irrigation)

Total 94.8 mm

- 13.3 mm on 18 August
- 8.4 mm on 23 August
- 14.8 mm on 26 August
- 14.2 mm on 10 September
- 12.1 mm on 21 September
- 16 mm on 7 October
- 16 mm on 28 October

Results

Phasic development

Variety, sowing date and the interaction between the two influenced phase development, time to flower and pod initiation. Generally, the growing season was longer in SD1. This might be due to the influence from a slower accumulation of growing degree days (GDD), shorter daylength and water treatment (Figure 1).

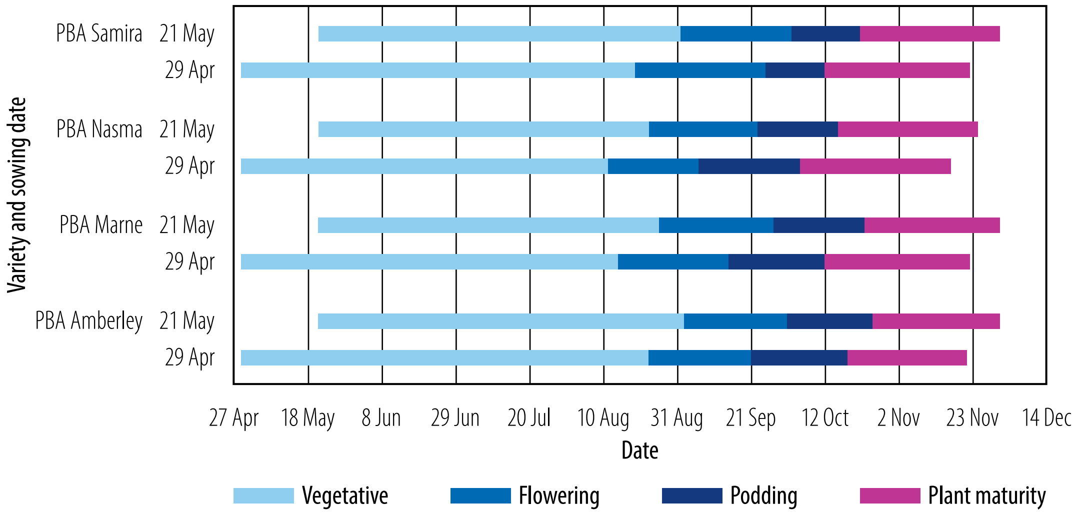

Figure 1 Influence of sowing date at Wagga Wagga on start and duration of key faba bean growth phases.

Days to plant establishment was affected by sowing date, which was longer in SD2 by 2.5 days due to cooler air and soil temperatures. Phenological traits (flowering and podding) were similarly affected by variety and sowing date, and their interaction. PBA Amberley$^{\Phi}$ was late flowering (50%) and podding (50%), with early sowing. However, the growth duration as measured by days to physiological maturity (Figure 1; Table 1) was influenced by all the main treatments (variety, sowing date and water treatment) and showed variety × sowing date; sowing date × water treatment; and variety × sowing date × water treatment interactions.

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Table 1 Phenological response to sowing date for 4 faba bean varieties at Wagga Wagga, 2021.
DTEst = days to establishment; DT50F = days to 50% flowering; DT50P = days to 50% podding; DTPM = days to physiological maturity; Dry = dryland treatment, Wet = water treatment.

Variety	SD	DTEst		DT50F		DT50P		DTPM	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
PBA Amberley	29 Apr	6.43	6.27	115.8	116.2	144.4	145.7	198.7	214.0
	21 May	8.33	7.76	104.0	104.1	134.2	132.7	192.0	196.0
PBA Marne	29 Apr	6.12	6.46	107.1	107.3	139.0	138.3	201.2	214.0
	21 May	8.15	9.76	97.0	96.6	129.5	130.0	192.0	196.0
PBA Nasma	29 Apr	7.60	5.70	104.3	104.3	130.6	129.8	197.0	207.0
	21 May	8.13	9.27	94.0	94.1	125.1	125.3	183.8	192.0
PBA Samira	29 Apr	6.19	4.88	112.0	112.2	148.8	149.8	200.7	214.0
	21 May	9.05	8.87	103.1	103.2	134.6	134.9	192.0	196.0
Variety	l.s.d.	n.s.		0.17		1.14		0.54	
SD	l.s.d.	0.91		0.30		0.94		0.38	
Water treatment	l.s.d.	n.s.		n.s.		n.s.		0.38	
Variety × SD	l.s.d.	n.s.		0.31		2.24		0.76	
Variety × water treatment	l.s.d.	n.s.		n.s.		n.s.		n.s.	
SD × water treatment	l.s.d.	n.s.		n.s.		n.s.		0.53	
Variety × SD × water treatment	l.s.d.	n.s.		n.s.		n.s.		1.07	

l.s.d. = least significant difference; n.s. = not significant.

Grain yield

The main treatments (variety, sowing date and water treatment) affected grain yield, biomass, harvest index, hundred seed weight and lodging scores (Table 2). For biomass accumulation, variety × sowing date and sowing date × water treatment interactions were also observed. Late sowing and dry treatment also resulted in lower biomass accumulation. Seed weight showed variety × sowing date; variety × water treatment; and sowing date × water treatment interactions. Variety × sowing date interactions were observed for grain yield.

PBA Marne$^{\phi}$ and PBA Nasma$^{\phi}$ had the highest grain yield (5.40 t/ha and 5.38 t/ha, respectively) when averaged over sowing date and water treatments, significantly more than PBA Amberley$^{\phi}$ and PBA Samira$^{\phi}$ (Table 2). Sowing on 29 April (SD1) in the optimum window achieved a grain yield of 5.19 t/ha with an increase of 13% compared with 4.6 t/ha when sowing was delayed until 21 May (SD2) (Table 2). The 95 mm of water applied in the water treatment increased grain yield across all varieties by 22%, from 4.42 t/ha to 5.38 t/ha (Table 2).

Harvest index, the ratio of grain yield to total biomass, displayed both variety × sowing date and water treatment interactions. Both PBA Nasma$^{\phi}$ (0.48) and PBA Marne$^{\phi}$ (0.48) had a significantly higher harvest index than either PBA Amberley$^{\phi}$ or PBA Samira$^{\phi}$ (both at 0.41) (Table 2). Harvest index increased significantly with delayed sowing, from 0.41 to 0.48 (Table 2).

PBA Samira$^{\phi}$ lodged more than the other varieties, it was also more pronounced in the water treatment and SD1. All the two-way and three-way interactions were observed for lodging.

Table 2 Biomass, grain yield and lodging response of 4 faba bean varieties for different sowing dates and water treatments at Wagga Wagga, 2021. *Dry = dryland treatment, Wet = water treatment.*

Variety	SD	Biomass (t/ha)		Hundred seed weight (g)		Grain yield (t/ha)		Harvest Index		Lodging score*	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
PBA Amberley	29 Apr	11.88	12.70	56.76	56.18	4.17	5.04	0.35	0.40	1.30	5.47
	21 May	8.46	9.98	61.64	62.65	3.60	4.53	0.43	0.45	1.19	3.50
PBA Marne	29 Apr	13.04	13.76	55.39	56.00	5.37	6.50	0.41	0.47	2.11	5.73
	21 May	8.49	10.60	54.32	58.85	4.15	5.58	0.49	0.53	1.15	2.32
PBA Nasma	29 Apr	12.39	12.58	59.56	65.77	5.58	5.89	0.45	0.47	1.65	3.24
	21 May	8.46	11.21	55.91	62.35	4.34	5.69	0.51	0.51	1.13	1.65
PBA Samira	29 Apr	12.21	12.08	57.25	56.65	4.35	4.63	0.35	0.38	2.40	7.58
	21 May	8.40	11.46	57.90	63.70	3.81	5.13	0.45	0.45	2.55	3.55
Variety	l.s.d	0.49		1.21		0.26		0.011		0.46	
SD	l.s.d	0.98		1.16		0.45		0.013		0.99	
Water treatment	l.s.d	0.99		1.27		0.44		0.020		0.87	
Variety × SD	l.s.d	0.93		1.75		0.46		0.016		0.85	
Variety × water treatment	l.s.d	n.s.		1.69		n.s.		0.019		0.80	
SD × water treatment	l.s.d	1.39		1.33		n.s.		0.02		1.23	
Variety × SD × water treatment	l.s.d	n.s.		n.s.		n.s.		n.s.		1.24	

l.s.d. = least significant difference; n.s. = not significant; * lodging score: 1 = low, 9 = high.

Summary

Seasonal conditions significantly influenced phenology and grain yield quality responses to sowing date and water treatment in 2021. Mild temperatures combined with above average soil moisture throughout the growing season masked the management practices, although varietal differences were evident. The increased biomass due to early sowing and water addition increased lodging incidence. While this is unusual it is probably due to the favourable end-of-season conditions, which did not present the abiotic stresses such as heat and moisture stress, commonly encountered at this site.

Acknowledgements

This experiment was part of the 'Matching adapted pulse genotypes with soil and climate to maximise yield and profit, with manageable risk in Australian cropping systems' project, BLG118, 2020–22, a joint investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

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The effect of sowing date and irrigation management on faba bean – Leeton 2021

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Key findings

- Sowing faba bean on 29 April (sowing date one – SD1) achieved a higher grain yield compared with sowing on 21 May (SD2).
- Irrigating faba bean with 2 spring irrigations on a border check layout increased grain yield when compared with rainfed.
- PBA Nasma⁽ᵇ⁾ was the highest yielding variety achieving 9.36 t/ha when averaged across both sowing dates and irrigation treatments.

Keywords faba bean, 2021, Leeton, sowing date, irrigation

Introduction

To maximise faba bean productivity and yield, it is important to optimise sowing time and the amount of applied irrigation water. Faba bean is affected by a range of abiotic stresses such as moisture stress and extreme temperatures (both low and high). An irrigated faba bean experiment was established at Leeton Field Station (LFS) in 2021 to determine the effect of sowing time and irrigation on 4 varieties of faba bean in southern NSW. This paper reports the findings from the 2021 experiment.

Site details

Location	Leeton Field Station
Soil type	Grey vertosol
Previous crop	Barley
Rainfall	137 mm (1.4 ML)
Starter fertiliser	120 kg/ha Utiliser pulse mix (nitrogen [N]:7.48, phosphorus [P]:17.64, potassium [K]:6.24, calcium [Ca]:6 4, zinc [Zn]:0.32).
Herbicides	• 1.7 L/ha Trilogy® (480 g/L trifluralin) (SD1 on 1 June and SD2 on 11 June). • 1.2 kg/ha Terbyne® Xtreme® (875 g/L terbuthylazine) (SD1 on 1 June and SD2 on 11 June). • 0.1 L/ha Verdict® (520 g/L haloxyfop) (SD1 only on 28 July). • 0.19 mL/ha Leopard® (200 g/L quizalofop-p-ethyl) (SD2 only on 13 August).
Fungicide	• 600 mL/ha Aviator® Xpro® (150 g/L prothioconazole and 75 g/L bixafen) (22 June). • 2.2 kg/ha Dithane® (750 g/kg mancozeb) (13 July). • 1.0 L/ha Veritas® (200 g/L tebuconazole and 120 g/L azoxystrobin) (29 July). • 500 mL/ha Howzat® (500 g/L carbendazim) (7 applications from 22 August to 20 October).

Harvest dates	• Hand harvested cuts were conducted from 3 November to 23 November. • All plots were machine harvested on 14 December.

Treatments

The experiment included 4 varieties, 2 sowing dates and 2 irrigation treatments (Table 1) replicated 4 times. The experiment was a split-split plot design with irrigation treatment as main plots, sowing date as subplots and varieties randomised within the subplots.

Table 1 Varieties, sowing dates and irrigation treatments evaluated in the LFS faba bean experiment, 2021.

Treatment		Comment
Variety	PBA Amberley⌽	Mid season variety released in 2020 and recommended for high rainfall areas of southern NSW
	PBA Marne⌽	Shorter season variety released in 2018 and recommended for lower rainfall areas
	PBA Nasma⌽	Large seed variety released in 2015 and recommended for northern NSW
	PBA Samira⌽	Mid season variety released in 2014 and recommended for southern NSW
Sowing date (SD)	SD1: 29 April 2021	Very early in the recommended sowing window (irrigated)
	SD2: 21 May 2021	Late in recommended sowing window (irrigated)
Irrigation	Irrigated	Two spring irrigations: 16 September and 21 October
	Non-irrigated	No spring irrigations applied

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Trial establishment

The whole paddock was pre-irrigated 5 days before SD1 to provide a full moisture profile across the experiment location. It was estimated that the irrigated treatments received a total of 447 mm, which included rainfall, pre-irrigation and spring irrigation, while the non-irrigated treatments received an estimated 289 mm, including rainfall and pre-irrigation only (Table 2).

Table 2 Rainfall and estimated irrigation quantity for the LFS faba bean experiment, 2021.

Irrigation and rainfall	Irrigated treatments	Non-irrigated treatments
Pre-irrigation	150 mm (1.5 ML)	150 mm (1.5 ML)
In season rainfall	137 mm (1.4 ML)	137 mm (1.4 ML)
Irrigation: 16 September	80 mm (0.80 ML)	0 mm
Irrigation: 21 October	80 mm (0.80 ML)	0 mm
Total	447 mm (4.5 ML)	289 mm (2.9 ML)

Rainfall data was sourced from an in-crop weather station located at LFS and supplied by Cropsol.
Irrigation quantities were estimated from experience conducting previous experiments where quantities were measured.

Assessments

At physiological maturity a 2 m^2 biomass cut was collected to determine total above ground biomass. Maximum grain yield, harvest index and hundred seed weight were calculated from the plant cut taken at maturity.

Results

Grain yield

PBA Nasma⌽ was the highest yielding variety with 9.36 t/ha when averaged over sowing date and irrigation treatments, significantly more than the other 3 varieties (Table 3). PBA Marne⌽ was the second highest yielding variety with 8.62 t/ha. PBA Amberley⌽ and PBA Samira⌽ had similar yields with 8.01 t/ha and 8.26 t/ha, respectively (Table 3). The late April sowing (SD1) achieved a maximum grain yield of 9.31 t/ha. This reduced by 16%, to 7.83 t/ha when sowing was delayed until late May (SD2) (Table 4). Applying 2 spring irrigations increased the maximum grain yield from 7.63 t/ha for non-irrigated treatments to 9.51 t/ha for irrigated treatments, when averaged over variety and sowing date (Table 5).

Table 3 Variety results averaged across all sowing dates and irrigation treatments in the LFS faba bean experiment, 2021.

Treatments	Maximum grain yield (t/ha)	Total biomass (t/ha)	Harvest index (%)	Hundred seed weight (g)	Protein (%)
PBA Nasma⏀	9.36	17.88	52.7	77.33	11.55
PBA Marne⏀	8.62	16.76	51.3	68.99	12.42
PBA Amberley⏀	8.01	16.21	49.6	65.44	12.04
PBA Samira⏀	8.26	16.21	51.0	70.58	12.29
l.s.d. (P<0.05)	0.44	0.58	1.2	1.76	0.39

l.s.d. = least significant difference.

Total biomass

PBA Nasma⏀ achieved the highest average total biomass at 17.88 t/ha when averaged over the 2 sowing dates and 2 irrigation treatments (Table 3). PBA Amberley⏀ and PBA Samira⏀ recorded the lowest accumulated biomass at 16.21 t/ha each, which was similar to the 16.76 t/ha of biomass accumulated by PBA Samira⏀ (Table 3).

When sown on 29 April (SD1), at the beginning of the optimal sowing window, the average accumulated biomass was 18.59 t/ha (Table 4). When sowing was delayed until 21 May (SD2), the total accumulated biomass was 14.94 t/ha, a reduction of 19.5% compared with SD1 (Table 4). The irrigated treatment produced significantly more total biomass (18.28 t/ha) than the non-irrigated treatment (15.25 t/ha), an increase of 19.8% when averaged across all varieties and sowing dates (Table 5).

Table 4 Sowing date results averaged across all variety and irrigation treatments in the LFS faba bean experiment, 2021.

Treatments	Maximum grain yield (t/ha)	Total biomass (t/ha)	Harvest index (%)	Hundred seed weight (g)	Protein (%)
SD1: 29 April	9.31	18.59	49.9	73.66	12.1
SD2: 21 May	7.83	14.94	52.4	67.51	12.0
l.s.d. (P<0.05)	0.56	0.74	1.3	1.31	n.s.

l.s.d. = least significant difference.

Harvest index

Harvest index is the proportion of the total biomass that is converted into grain yield. Harvest index for the 4 varieties ranged from 49.6% to 52.7% (Table 3). PBA Nasma⏀ converted the highest percentage of total biomass to grain yield with 52.7% (Table 3), which was significantly higher than all other varieties, whilst PBA Amberley⏀ at 49.6% had the lowest of all the varieties (Table 3).

Sowing date significantly affected the harvest index of the crops. When varieties were sown on 29 April (SD1), the harvest index was 49.9%, significantly lower than 52.4% for the later sowing in May (SD2) (Table 4). The higher conversion of biomass to grain yield when sown later contrasted the lower accumulated biomass. The higher harvest index at the later sowing (SD2) did not fully compensate for the lower accumulated biomass. Spring irrigation increased the conversion of total biomass into grain yield with 52.1% and 50.1% for irrigated and non-irrigated treatments, respectively (Table 5).

Table 5 Irrigation treatment results averaged across all variety and sowing date treatments in the LFS faba bean experiment, 2021.

Treatments	Maximum grain yield (t/ha)	Total biomass (t/ha)	Harvest index (%)	Hundred seed weight (g)	Protein (%)
Irrigated	9.51	18.28	52.1	71.97	12.23
Non-irrigated	7.63	15.25	50.1	69.20	11.92
l.s.d. (P<0.05)	0.58	0.77	n.s.	1.37	n.s.

l.s.d. = least significant difference.

Hundred seed weight

PBA Nasma[Ф] had the highest hundred seed weight at 77.33 g and was significantly heavier than all other varieties. In contrast, PBA Amberley[Ф] recorded the lowest hundred seed weight at 65.4 g (Table 3).

Sowing date had a significant effect on the hundred seed weight. Crops sown on 29 April (SD1) had a hundred seed weight of 73.66 g with an 11.2% reduction in seed size to 67.51 g when sown on 21 May (SD2) (Table 4).

Applying a spring irrigation treatment significantly increased hundred seed weight from 69.2 g to 71.97 g over the non-irrigated treatment when averaged across all varieties (Table 5).

Pulses

Summary

PBA Nasma[Ф] was the best performing variety, achieving the highest grain yield when averaged across sowing dates and irrigation treatments. PBA Nasma[Ф] also had the largest seed with a hundred seed weight of 77.3 g, highest total biomass (17.88 t/ha) and largest harvest index (52.7%) when compared with the other 3 varieties.

Sowing date had a significant effect on grain yield, reducing by 1.48 t/ha, when sowing was delayed from 29 April to 21 May 2021. Both the 2020 and 2021 irrigated faba bean experiments demonstrated significant yield increases with a late April sowing time when compared with a mid May sowing time. Sowing in late April also had an increasing effect on biomass by 19% and hundred seed weight by 8%, in contrast harvest index reduced by 4%.

Applying 2 spring irrigations increased yield by over 24% to 9.51 t/ha, through increased biomass by 19.8%, harvest index by 2% and hundred seed weight by 4% when compared with the non-irrigated treatments.

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Cereal disease management and diagnostics

What we learned in 2021 to improve management in 2022

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Key findings

- Favourable climatic conditions in 2021 resulted in the increased prevalence of a range of cereal diseases across NSW, especially the wheat leaf diseases stripe rust, septoria tritici blotch (STB) and yellow leaf spot (YLS).
- In combination with increased cereal stubble loads produced in 2021, pathogen levels are likely to be elevated again in 2022.
- Predicted La Niña conditions over summer will maintain or increase the risk of stripe rust in 2022.
- Multiple stripe rust pathotypes were prevalent across NSW in 2021. Keep up to date with the latest varietal resistance ratings.
- Minimise disease impacts in 2022 by using an integrated approach to management.
- NSW DPI plant pathologists can assist with correct diagnosis and advice on appropriate management options.

Keywords diagnosis, leaf, soil-borne, virus, stripe rust

Introduction

NSW DPI provides a free cereal disease diagnostic service to cereal growers and their advisers as part of NSW DPI and GRDC Grains Agronomy and Pathology Partnership (GAPP) integrated disease management (IDM) projects. Evidence-based methods are used to confirm diagnosis that include a combination of visual symptoms, crop management history, paddock distribution and recovering/identifying the causal pathogens (microscopy, humid chamber or plating). Any suspect virus samples are confirmed using ELISA antibody testing at the NSW DPI Elizabeth Macarthur Agricultural Institute at Menangle.

Wheat, barley and oat rust samples (stripe, leaf and stem) are sent to the Australian Cereal Rust Control Program (ACRCP). Sample submission to ACRCP helps to track pathotype populations and distribution across the cropping belt of NSW and Australia. This includes a new interactive map (Australian Cereal Rust Survey 2021 Sample Map - Google My Maps) that is regularly updated throughout the growing season by the ACRCP. Growers can access this resource to see which pathotypes dominate in their region. This can be very important to guide in-crop management decisions given 5 different stripe rust pathotypes were present at varying levels across NSW in 2021. Individual wheat varieties can have vastly different reactions to these pathotypes, so identifying the dominant pathotype for a particular region and time provides useful guidance for developing appropriate seasonal in-crop management.

The IDM projects also record disease enquiries received from growers and advisers throughout each season. These project activities provide NSW cereal producers with correct in-crop disease diagnosis and independent management advice. Correct diagnosis limits adverse economic impacts by avoiding unnecessary in-crop fungicide application.

Collating this data across NSW provides an annual 'snapshot' of the key biotic and abiotic constraints to cereal production (Table 1).

Table 1 Cereal diagnostics and enquiries processed across NSW between 2019 and 2021. *Disease/issues are ranked in order of frequency in 2021*.

Disease/issue	Number processed		
	2021	2020	2019
Stripe rust (wheat)	343	194	13
Fusarium crown rot	99	61	14
Septoria tritici blotch	56	17	13
Yellow leaf spot	56	10	4
Other non-disease (e.g. soil constraint, leaf blotching/mottling)	53	34	24
Spot form of net blotch	50	65	32
Leaf rust (wheat)	37	35	2
Take-all	33	16	1
Common root rot	26	2	3
Frost damage	24	45	4
Rusts: crown and stem (oats)	24	29	4
Wheat streak mosaic virus	23	3	1
Net form of net blotch	20	23	0
Physiological/melanism	20	65	10
Fusarium head blight	18	10	0
Nutrition	18	16	2
Wheat powdery mildew	17	53	1
Seedling root disease complex (*Pythium*, crown rot, *Rhizoctonia*, take-all)	13	8	2
Loose smut	11	9	1
Rhizoctonia	9	12	7
Barley powdery mildew	8	12	0
Herbicide	7	28	6
Scald	7	65	4
Bacterial blight (other cereals)	4	30	0
Barley yellow dwarf virus	4	19	1
Leaf rust (barley)	3	0	0
Red leather leaf	3	1	7
Septoria oats	3	3	2
Oat leaf blotch	2	0	0
Other minor diseases	2	5	2
Ring spot	2	0	1
Barley grass stripe rust	2	20	1
Bacterial blight (oats)	1	22	3
Total	998	912	165

Individual seasons have a strong influence on the demand for cereal diagnostic support, with over five times the number of activities in the wetter 2020 and 2021 seasons compared with much drier conditions in 2019 (Table 1). These increases were primarily due to more conducive conditions for cereal leaf disease development.

In 2021, wheat stripe rust maintained top ranking as the most diagnosed and queried cereal disease with 34% of the total activities. Fusarium crown rot in winter cereals ranked second followed by septoria tritici blotch (STB) and yellow leaf spot (YLS) tied for third. Other 'non-disease' related issues ranked fourth, which emphasises the ongoing importance of correct diagnosis.

Are you getting a correct diagnosis?

Importantly, 13% of activities in 2021, 21% in 2020 and 28% in 2019 were not related to disease. These samples were either diagnosed as being plant physiological responses to stress, frost damage, herbicide injury, related to crop nutritional issues or other non-disease issues. All 132 samples in 2021 were submitted as suspected of having disease issues. This highlights the ongoing importance of the diagnostic service provided by these projects to NSW growers and their advisers to support correct identification to enable implementing of appropriate management strategies.

A second opinion from a plant pathologist can ensure correct diagnosis – (see contact details below).

What we saw in 2021

Wheat stripe rust

Wheat stripe rust made up 34% of activities in 2021, far exceeding 21% in 2020 and 8% in 2019. The conducive 2020 season enabled stripe rust inoculum to build up, which was then hosted by wheat volunteers over the wet 2020/2021 summer. Resulting high inoculum levels combined with the early opportunity for sowing grazing wheat kickstarted the epidemic for the 2021 cropping season.

There were 2 predominate pathotypes identified in NSW in 2021, along with 3 other pathotypes with reduced incidence. The predominate pathotypes identified by the Australian Cereal Rust Survey in 2021 were 198 E16 A+ J+ T+ 17+ (198) and 239 E237 A– 17+ 33+ (239), making up around 90% of the samples submitted (R. Park, 2021 pers. comm). The other pathotypes identified to a lesser extent than 198 and 239 in 2021 included 134 E16 A+ 17+, 134 E16 A+ 17+ 27+ and 64 E0 A–.

Each of these pathotypes can affect a particular variety (host) differently. This is due to the genetic makeup of the host plant, i.e. the resistance genes within the plant, and the individual pathotypes virulence or avirulence status on those genes. It is important to keep up to date with the latest variety resistance ratings as the ratings can change from year to year.

Disease resistance ratings are developed through the National Variety Trials (NVT) pathology screening project. These ratings are released annually on the GRDC NVT website (https://nvt.grdc.com.au) and in state-based sowing guides, such as the NSW DPI Winter crop variety sowing guide (https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide). There have been some reductions to the ratings of some varieties for the 2022 season (Table 2).

Table 2 Disease rating reductions for the 2022 season.

Disease rating reductions	
Significant reductions (more than one level)	**Minor reductions (one level only)**
Astute[PBR] (triticale)	Ascot[PBR]
Boree[PBR]	Caparoi[PBR]
Catapult[PBR]	Chief CL Plus[PBR]
Coolah[PBR]	Corack[PBR]
Coota[PBR]	Cutlass[PBR]
Devil[PBR]	Denison[PBR]
Fusion (triticale)	DS Tull[PBR]
KM10 (triticale)	Emu Rock[PBR]
LongReach Oryx[PBR]	Illabo[PBR]
Rockstar[PBR]	Kinsei[PBR]
Sheriff CL Plus[PBR]	LongReach Flanker[PBR]
Sting[PBR]	LongReach Havoc[PBR]
Valiant CL Plus[PBR]	LongReach Impala[PBR]
Vixen[PBR]	LongReach Kittyhawk[PBR]
Yitpi[PBR]	LongReach Mustang[PBR]
	LongReach Nighthawk[PBR]
	LongReach Nyala[PBR]
	Mitch[PBR]
	RGT Ivory[PBR]
	SEA Condamine[PBR]
	Sunblade CL Plus[PBR]
	Suncentral[PBR]
	Sunmaster[PBR]

Wheat streak mosaic virus (WSMV)

Wheat streak mosaic virus was more prevalent in 2021 with 23 confirmed cases, up from 3 in 2020 and one in 2019. The majority of these came from the high rainfall, mixed farming regions of southern NSW around the Young, Harden and Cootamundra regions. However, cases were reported as far north as Cumnock in central NSW. WSMV is transmitted by wheat curl mites (WCM) that host on cereal volunteers and grass weeds, and which were favoured by the mild wet 2020/2021 summer in cropping paddocks or nearby pasture paddocks. WCM migrate or are windblown into newly emerging crops where they transmit WSMV as they feed on seedling wheat plants. The earlier the infection occurs, the more severe the yield penalty. Early infection in young plants can cause death and as the season progresses, expression can include sterile empty heads, heads trapped in the boot due to leaf curling, and pinched grain. Early infections can be devastating as seen in 2005, with up to 80% loss observed in infected paddocks.

WSMV can be seed-borne at low infection (<1%) levels. On a paddock scale, this can still result in a considerable number of infected plants in the newly emerged wheat crop. Ideally, seed should not be retained from crops or areas of crops known to be infected with WSMV in 2021. Seed-borne transmission is a distinct risk for spreading WSMV into other paddocks or regions. It is expected the risk of WSMV will be further elevated in 2022.

Disease risk in 2022

Inoculum and disease risk levels for the 2022 season are elevated due to the conducive weather conditions in 2020 and 2021. Diseases require a susceptible host, a source of inoculum and conducive environmental conditions to develop.

Climatic conditions (rainfall, temperature and humidity) play a significant role in initiating and driving disease epidemics. Individual pathogens each have a specific set of climatic conditions that must be met to promote initial infection and favour disease development.

If 2022 is mild and wet, there is a higher risk of foliar disease epidemics. These include biotrophic diseases such as rusts and necrotrophic diseases such as STB and YLS in wheat; and the spot form net blotch (SFNB), net form net blotch (NFNB) and scald in barley. These conditions will also favour soil-borne diseases such as take-all and *Pythium*. If the 2022 season is drier, there will likely be a decrease in foliar diseases and an increase in root diseases, such as fusarium crown rot and *Rhizoctonia* where the drier conditions favour expression.

The outlook for the 2021/2022 summer is wet and mild conditions, much like 2020/2021. This will favour the 'green bridge'. The green bridge is the presence of volunteer cereals and weeds in a paddock over the summer and autumn periods. Green bridges can harbour diseases, insect pests and viruses. If the forecast is correct and if the green bridge is not controlled, this will provide the ideal platform for biotrophs such as wheat stripe rust epidemics to initiate early in the 2022 season.

The final inoculum consideration is from seed-borne diseases and viruses such as bacterial blight, smuts, bunts, fusarium-infected grain and WSMV. Sourcing clean seed for sowing in 2022, that is, not from crops infected in 2021, is important to reduce risk of these diseases.

Integrated disease management for 2022

There are integrated management strategies that growers can use to reduce disease pressure from foliar, soil and stubble-borne diseases.

1. Risk identification before sowing

Be proactive instead of reactive. Consult paddock notes, management plans and rotation sequences from previous years to identify known and potential disease issues. Gain an understanding of your underlying inoculum levels through the PreDicta®B DNA-based testing method. PreDicta®B quantifies a wide range of pathogen levels in your paddock and provides an associated risk level. Alternatively, 2021 cereal stubble can be submitted to the NSW DPI Tamworth laboratory for free plating of fusarium crown rot, common root rot and take-all risk (contact Dr Steven Simpfendorfer, details below). This provides the information necessary to develop management plans and identify changes if the associated risk is unacceptable. It is recommended that growers and advisers review extension materials and disease bulletins as well as assess stubble for disease indicators such as formation of yellow leaf spot or net blotch fruiting bodies (raised small black lumps on the outside of stubble).

Assess the green bridge risk!!

2. Crop rotation

Sow break crops for one or more years between cereal crops. Break crops include pulses, canola and grass-free pasture legumes (e.g. lucerne). This will help to break down any cereal pathogen inoculum present. Grass weed control is vital in break crops as most grass weeds are alternative hosts of winter cereal pathogens.

As inoculum levels in 2022 are likely to be elevated, sowing cereal-on-cereal will increase the risk of yield loss. If there is a perceived or known disease issue in a paddock, switch out to a break crop to eliminate yield loss and drive down inoculum pressure.

3. Variety selection

Select varieties that provide the best resistance ratings to known or likely disease issues. This gives wheat crops the best chance to optimise yield in the presence of a pathogen. If there are multiple known disease issues, select the variety with the best resistance rating to the potentially most damaging disease.

This is particularly important for wheat stripe rust in 2022 as many widely grown wheat varieties have had their resistance levels to new pathotypes reduced and therefore will require more intensive management. Effective varietal selection will reduce the likelihood of requiring repeated in-crop fungicide applications, which will be a benefit in 2022 with potentially tight fungicide supply, much like the 2021 cropping season.

4. Stubble management

Retained stubble systems are driving the prevalence of soil and stubble-borne diseases in NSW farming systems. After successive high yielding years in 2020 and 2021, heavy cereal stubble loads exist in many paddocks across NSW. The stubble provides a source of inoculum for necrotrophic foliar diseases such as STB, YLS in wheat, and SFNB, NFNB and scald in barley. Cutting height at harvest can affect the physical amount of stubble left standing in the paddock for pathogens such as *Fusarium* to further vertically colonise post harvest. Other management options for reducing stubble-borne diseases include burning, mulching, grazing, baling stubble or incorporating the stubble into the soil.

Burning might have a minimal effect on the inoculum levels of fusarium crown rot, common root rot and take-all, as most of the inoculum is in the crown or root system below ground. The decision to burn cereal stubble should be weighed up against disadvantages such as nutrient loss, reduced storage of fallow moisture and increased erosion risk.

Lowering harvest cut height, mulching and incorporating stubble can reduce the amount of standing stubble, but can potentially also spread pathogen inoculum more uniformly across a paddock. The risk and benefits must be weighed up before undertaking these operations.

Inter-row sowing is another effective stubble management technique. This physically distances the plant from the previous stubble row, reducing contact with pathogens that cause soil and stubble-borne root diseases.

5. Volunteer cereals and grass weed control – the green bridge

Chemically or mechanically controlling cereal volunteers and weeds during the summer fallow period is critical to reducing the survival of rusts and insect virus vectors such as aphids or WCM. Controlling the green bridge reduces or breaks the inoculum cycle of diseases or lifecycle of virus vectors. Controlling volunteer cereals and grasses in non-crop areas such as fence lines, around dams, creek lines and silos is also important.

Controlling the green bridge is vital as a management tool for all cereal rusts. Stripe rust (especially the 198 pathotype) developed early in grazing wheats in 2021, particularly in DS Bennett⟨ϕ⟩. The disease survived on wheat volunteers over summer and infected these crops early, kick-starting what was a high-pressure stripe rust season, which then spread onto main season plantings. The 2022 season is potentially shaping up to be similar to 2021. If sowing grazing crops early in 2022, spray out volunteers and weeds well in advance (4 weeks) of sowing to delay the onset of stripe rust infections. As wheat stripe rust is highly wind dispersed, this approach is much more effective if adopted across a whole region. Note that the more susceptible a wheat variety is to stripe rust, the greater the need to control the green bridge.

Green bridge control will also reduce your risk of WSMV. This is critical as there are no effective in-crop management options for WCM. Early-sown grazing wheat crops are generally sown in the high rainfall, mixed farming regions of NSW, which are the same locations in which WSMV was prevalent in 2021. The WCM hosts on cereal volunteers and grass weeds and under ideal conditions can survive for 2 weeks without a host. One contributing factor to WSMV infections in 2021 was the knock-down herbicide spray being applied to paddocks just before sowing. The WCM was hosting on the green bridge (mainly volunteer wheat) in these paddocks, and by the time the herbicide spray had taken affect, the new wheat crop was emerging. The WCM moved off the senescing green bridge and straight onto emerging wheat plants, infecting large numbers of plants and continuing the cycle.

For this same reason, it is advised to spray out volunteers in any adjoining wheat paddocks from 2021 or fallow paddocks well in advance of sowing to avoid the same WCM migration pattern onto emerging wheat crops in 2022.

6. Grazing

Grazing can be a technique to reduce the incidence and severity of cereal foliar diseases. By grazing the crop, green leaf area is removed along with infected tissue present at the time. Grazing also reduces humidity within the crop by opening up the canopy and allowing airflow, thus creating an environment which is less conducive to leaf disease development.

Early crash grazing can be an option to reduce wheat stripe rust pressure. However, be mindful of grazing withholding periods if flutriafol was applied to starter fertiliser at sowing. If taking the grazing crop through to grain harvest, stock must be removed from the crop by GS31 to avoid yield penalties. Note that grazing is not as effective as a management strategy if infection is patchy, or stripe rust hotspots are already present in a crop.

7. Fungicide use

Due to the evolution of fungicide resistance in some cereal pathogens, such as *Zymoseptoria tritici* (STB) and *Blumeria graminis* f. sp. *tritici* (wheat powdery mildew – WPM) and the risk of further resistance development, it is essential that fungicide modes of action (MOA) are rotated if there is to be more than one fungicide application per year. This reduces the risk of resistance development in target and non-target pathogens.

Moving forward into 2022, changes in resistance ratings of widely grown varieties showing increased susceptibility to the 198 and 239 stripe rust pathotypes means fungicide management will have to change to suit. Widely grown varieties such as Catapult⊕, Coolah⊕, Coota⊕, Rockstar⊕ and Vixen⊕ have had their ratings drop by 2 or more levels. What this means is that a previously rated moderately resistant to moderately susceptible (MR–MS) variety is now classed as susceptible (S) and will require a more robust fungicide management package to what was used on that variety in previous years.

Due to the high inoculum pressure expected in the 2022 cropping season, the recommended fungicide regime for a susceptible or worse rated variety to stripe rust should include an up-front fungicide such as flutriafol on starter fertiliser at sowing, followed by a GS31 and GS39 in-crop fungicide application.

Alternatively, if an up-front fungicide is not used, a minimum of 2 in-crop fungicide applications should be planned, timed at GS31 and GS39. Earlier in-crop intervention might be needed if stripe rust appears before GS31.

Fungicide applications can be altered to suit another key growth stage such as flowering, seasonal conditions and outlook along with yield potential. Fungicide resistance management through rotation of MOA and individual triazole actives within season should also be considered (see AFREN – https://afren.com.au/).

8. Adequate nutrition

Ensure adequate nutrition is applied to optimise crop health and yield potential and balanced to meet seasonal conditions. Applying too much nitrogen can cause excessive canopy biomass to develop, exacerbating foliar diseases. Increased nitrogen application can also increase moisture stress during anthesis and grain filling if in-crop rainfall or stored soil water supply is limited. Late season water stress can also exacerbate the expression of fusarium crown rot in infected crops.

9. In-crop monitoring

Inspecting cereal crops for the presence and extent of disease development and the resulting management decisions are vital to economic performance. Missed fungicide spray timings on susceptible varieties can have significant yield penalties in conducive seasons.

Wheat stripe rust can cycle every 10–14 days at optimum average daily temperatures of around 15 °C (maximum + minimum temperature divided by 2). Due to changes in resistance ratings of widely grown wheat varieties to stripe rust, regular monitoring is required to identify early infections as fungicides are considerably more effective when used in a preventative rather than curative strategy.

Early disease detection through regular monitoring is therefore important. Irregular inspections might miss the expression of disease after infection.

Conclusions

Overall, cereal crop production was above average across a large proportion of NSW in 2021 even though late rain affected quality in some areas. The 2022 season is already shaping as another favourable year for crop production with high soil moisture levels already accumulating. Cereal disease risk is likely to be higher due to pathogen build-up in 2020 and 2021. Well-planned integrated management strategies in the face of higher input costs and potential tight fungicide availability in 2022 will help to minimise disease levels while maximising profitability. NSW DPI can assist with correct diagnosis and discuss management options before sowing and as required throughout the season.

Reference

Park R (December 2021) Sydney University Australian Cereal Rust Survey, personal communication.

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Crop protection

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Variety resistance has little effect on ascospore production by wheat pathogens *Zymoseptoria tritici* (STB) and *Pyrenophra tritici-repentis* (YLS)

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Key findings

- *Zymoseptoria tritici* and *Pyrenophra tritici-repentis*, the disease-causing pathogens of septoria tritici blotch (STB) and yellow leaf spot (YLS), can produce ascospores on wheat stubble regardless of their resistance status.
- Any infected wheat stubble has the ability to initiate an epidemic for up to 2 years.
- Reduce harvest cut height to limit *Z. tritici* colonising stubble.
- Excess harvest material must be removed from the paddock to produce a net reduction of *Z. tritici* inoculum.
- Minimise disease impacts by using an integrated approach to management.

Keywords septoria tritici blotch, yellow leaf spot, stubble, resistance, foliar, wheat

Introduction

Septoria tritici blotch (STB) caused by *Zymoseptoria tritici* and yellow leaf spot (YLS) caused by *Pyrenophora tritici-repentis* are major stubble-borne foliar diseases of wheat in the cropping regions of southern New South Wales (sNSW). The diagnostic activities and industry inquiries received in 2021 by NSW DPI pathologists revealed that STB and YLS were the third and fourth most queried diseases across the state. STB does not just infect wheat; durum and triticale are also STB hosts, but there are good levels of genetic resistance in triticale and generally in durum. Therefore, STB is not considered a major disease of these crops in Australia currently. Similarly, YLS also infects triticale and durum, but there are varieties with useful levels of resistance. STB and YLS do not cause significant disease in any other major cereal crop.

Z. tritici and *P. tritici-repentis* have a fungal structure produced on wheat stubble (pseudothecia) that releases airborne spores (ascospores) when environmental conditions are conducive. The ascospores produced can spread by wind to infect host crops. *Z. tritici* ascospores can travel further than *P. tritici-repentis* ascospores. Even after a non-host break crop (e.g. canola) is sown in a paddock, any remaining wheat stubble residues can still be an inoculum source and infect the emerging wheat crop.

STB lesions will appear up to 28 days after infection and produce pycnidia (small black structures inside tan leaf lesions that give a speckled appearance). The pycnidia produce an asexual spore called conidia. The conidia are then splash dispersed by rainfall within the wheat canopy causing new infections and further driving the epidemic. Recent research completed at Wagga Wagga Agricultural Institute (WWAI), found that between 20% and 45% yield loss is possible in a susceptible variety (Baxter, Simpfendorfer and Milgate 2022).

In contrast, YLS lesions are oval, or lens shaped, with a tan centre and chlorotic yellow margin around the lesion. In severe infections or in conducive environmental conditions, lesions can coalesce into each other. The important distinguishing feature between YLS and STB lesions is that YLS do not contain the black pycnidia. *P. tritici-repentis* does, however, produce asexual conidia spores that can be wind dispersed into the upper canopy of the crop and greater distances to infect other susceptible cereal crops. *P. tritici-repentis* has a shorter incubation period than *Z. tritici*, approximately 7 days, resulting in multiple disease cycles per season when environmental conditions are ideal. Fresh conidia spores can be produced every 24 hours on the surface of necrotic YLS lesions. Research conducted at WWAI in 2015 (Milgate and Goldthorpe 2015) found that YLS can cause up to a 26% yield loss in a susceptible variety.

The results of 2 experiments are discussed in this paper, the first demonstrates that variety resistance has no effect on ascospore development for either *Z. tritici* or *P. tritici-repentis*. Further to this, we observed that the in-season disease severity also has no effect on the ability of these necrotrophic pathogens to survive and produce inoculum. The second set of results show how growers can use simple harvest management techniques to mitigate against this survival feature of these important pathogens and reduce the amount of inoculum in paddocks.

Method

Experiment 1

In simple terms, resistance can be thought of as the ability of a plant to limit damage caused by pathogen infection. Current commercial cereal and pulse varieties are screened annually for their resistance to a range of diseases through the National Variety Trials (NVT) system. A sliding resistance rating scale, ranging from resistant (R) to very susceptible (VS) is applied to each entry. A set of 30 commercial wheat varieties were selected from the NVT system and sown in 2 separate field nurseries to assess the foliar disease progression of STB and YLS in varieties sown at different times. There were 4 sowing dates, each approximately 2 weeks apart, starting in early April of each year (Table 1). The nurseries were a randomised complete block design with 3 repetitions. The entries were sown into short rows, 1.5 m long, with 2 entries and a susceptible check per plot. The entries were visually assessed for foliar disease progression, with the trait 'percentage of whole plant coverage' assessed fortnightly during the growing season (data not shown). The experiments were not harvested for yield.

Table 1 The sowing date windows for STB and YLS nurseries, 2019 and 2020.

Sowing date (SD)	Across seasons (2019–2020) sowing windows for STB and YLS nurseries
SD1	8 April
SD2	21–24 April
SD3	5–6 May
SD4	19–22 May

The second part of Experiment 1 quantified the number of ascospores released from the wheat stubble. This was to determine the risk of the stubble as an inoculum source for the proceeding wheat crop and to quantify any difference in the number of ascospores released from residual stubble of varieties that have a range of resistance ratings and infections during the season.

The standing stubble was left to naturally weather and mature in the paddock after harvest. Due to operational space restraints, the stubble had to be collected before sowing in the following year and placed into breathable calico bags, then secured to a paddock fence line to continue the weathering and maturing process.

Four varieties out of the 30 assessed for foliar disease progression, were selected to quantify ascospore release from the stubble. The selected varieties had a range of resistance ratings to STB and YLS (Table 2). The spore release component of Experiment 1 was conducted under controlled conditions in the laboratory. To stimulate the release of spores from the stubble, 5 tillers per variety were soaked in water for 6 hours. The ascospores were then released from the pseudothecia on the stubble using air suction in a specially designed apparatus, affectionately named the 'spore liberator'. The stubble was in the spore liberator for 18 hours. The ascospores were captured on a microscope slide and counted manually using a microscope. This was repeated 44 times for each variety for each sowing date.

Table 2 Resistance ratings for the 4 varieties that were assessed for ascospore release under laboratory conditions.

Variety	Resistance rating to STB*	Resistance rating to YLS*
Axe⁽ᵈ⁾	S–VS	S
LongReach Kittyhawk⁽ᵈ⁾	MR–MS	MR–MS
LongReach Lancer⁽ᵈ⁾	MS	MS
Sunlamb⁽ᵈ⁾	MR	MR–MS

* as per *NSW DPI Winter crop variety sowing guide*.
Resistance ratings: MR = Moderately resistant; MR–MS = Moderately resistant to moderately susceptible; MS = Moderately susceptible; S = Susceptible; S–VS = Susceptible to very susceptible.

Treatments

Experiment 1

Each year, all entries were inoculated with stubble known to be infected with either *Z. tritici* or *P. tritici-repentis* to promote natural initial infection. Supplementary overhead irrigation was applied daily in short, regular bursts, to further drive the epidemic by maintaining leaf wetness and humidity within the crop canopy. Agronomically, all entries were treated the same within the growing year. There were no fungicides applied.

Experiment 2

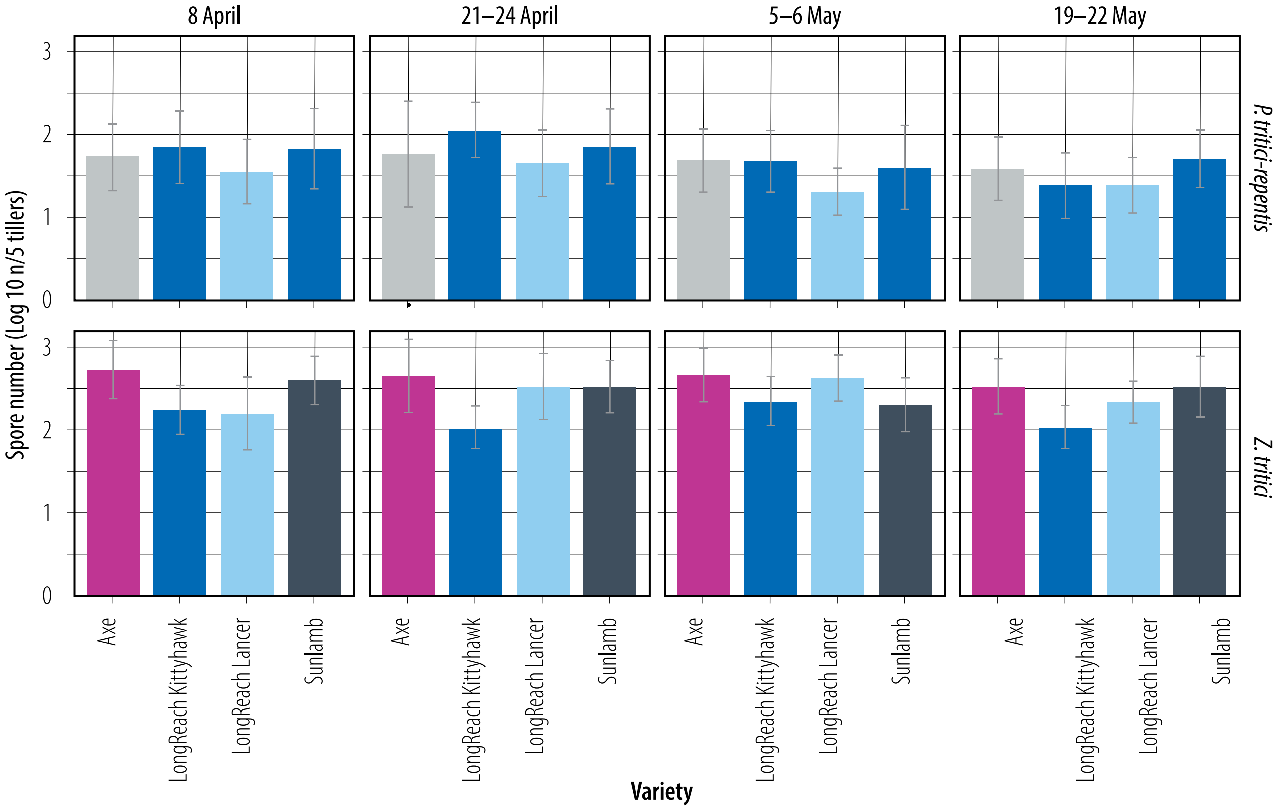
A single variety Beckom⁽ᵈ⁾, S–VS to STB was planted in 10 m^2 plots at WWAI during 2020. The experiment was inoculated with STB and maintained with supplementary irrigation as above. The plots were harvested at 3 heights, with the average cut height of treatments being 32 cm (high treatment), 24 cm (medium treatment) and 14 cm (low treatment) (Figure 2a). Each of the cut heights aimed to lower the straw length by one node on the mainstem. The stubble was weathered naturally in the paddock and collected during May 2021 and ascospore release counted as per Experiment 1. Spore releases from the different heights were repeated 96 times (Figure 2b).

Results

The ascospore release data collected over 2 years (Figure 1) shows that regardless of the variety's resistance rating, there is no significant difference ($P = 0.05$) across the 4 sowing dates, or within a sowing date between varieties, of the number of *Z. tritici* and *P. tritici-repentis* ascospores released from the stubble. In the case of STB, this means that an MR-rated variety is releasing the same amount of ascospores as an MR–MS, MS or S–VS-rated variety.

Generally, there were more *Z. tritici* ascospores released from the stubble than *P. tritici-repentis* ascospores. Across all sowing dates, the minimum number of *Z. tritici* ascospores released was Log10 score of 2.0, or over 100 ascospores per 5 tillers, with many reaching a Log10 score of 2.5, or approximately 300 ascospores per 5 tillers. In contrast, the *P. tritici-repentis* ascospores ranged between Log10 score 1.0 and 2.0: between 10 and 100 ascospores per 5 tillers. Further findings from experiments (data not shown) have shown that stubble infected with the STB-causing pathogen *Z. tritici*, can generate enough ascospores to initiate an epidemic 2 years after the wheat crop was grown. Again, this was irrespective of the variety resistance rating.

The foliar disease data (not shown) revealed an interaction with the ascospore release data. It showed that earlier sowing dates (SD1 and SD2) had a much higher level of foliar disease than the later sowing dates (SD3 and SD4), with SD1 having the highest disease levels and SD4 the lowest. For example, Axe⁽ᵈ⁾ in SD1 scored 85% STB disease severity while in SD4 the variety only scored 34%. However, this did not correlate to higher ascospore numbers released from the stubble from the earlier sowing dates (Figure 1) compared with the later sowing dates. The number of ascospores released within a single sowing date, remained relatively stable.



Resistance rating

- Moderately resistant (MR)
- Moderately resistant to moderately susceptible (MR–MS)
- Moderately susceptible (MS)
- Susceptible (S)
- Susceptible to very susceptible (S–VS)

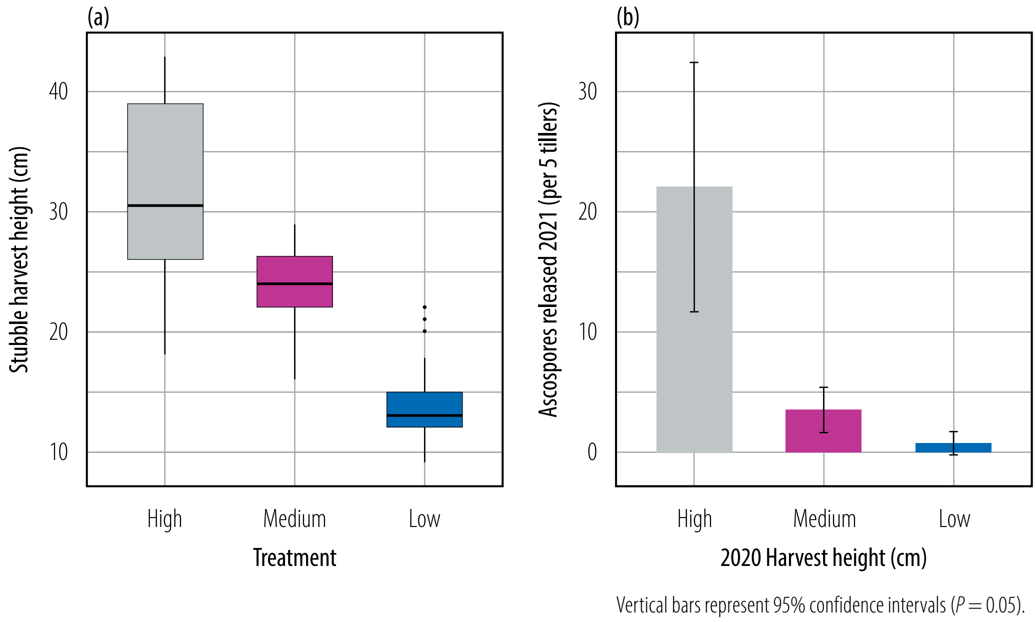
Note: The Log10 average combines all data from 2 years of spore release repetitions conducted in the laboratory.
There is no significant difference in the number of ascospores released between resistance ratings for both STB and YLS.
Log1 = 10 spores, Log 2 = 100 spores and Log 3 = 1000 spores.
Vertical bars represent 95% confidence intervals (*P* = 0.05).

Figure 1 The average Log10 number of *Zymoseptoria tritici* and *Pyrenophora tritici-repentis* ascospores released from wheat stubble, from 4 varieties with different resistance ratings to the diseases septoria tritici blotch (STB) and yellow leaf spot (YLS).

Figure 2a and 2b show results from Experiment 2, the STB stubble management experiment. Both figures are specific to STB and the results from these cannot be extrapolated to YLS.

Figure 2a shows the harvest cut heights imposed across the plots.

Figure 2b shows the reduced number of *Z. tritici* ascospores by lowering the harvest cut height. Using the 32 cm cut height as a base level, lowering the cut height to 24 cm reduced the number of ascospores produced from the stubble by 87%. When comparing the 32 cm cut height with the 14 cm cut height, the number of ascospores released from the stubble was reduced by 97%.



Note: average harvest cut heights for treatments: High – 32 cm, Medium – 24 cm and Low – 14 cm.

Figure 2 (a) Box plot showing the harvest cut height in centimetres (cm) of the high, medium and low treatments for the 2020 STB stubble management experiment. (b) The number of *Zymoseptoria tritici* ascospores released from 5 tillers from the 3 stubble cut height treatments. This figure displays the reduction in ascospore numbers as the harvest cut height decreases.

Discussion

It is commonly accepted that the more susceptible a variety is to a particular disease, the greater the inoculum risk the stubble or volunteers pose for the following season. This remains true for diseases such as stripe rust, but the spore release data collected over the past 2 years in these experiments has shown that this might not be the case for STB and YLS. This has implications for crop rotation, and sequences and stubble management. In sNSW, the cropping sequence is dominated by cereal–canola–cereal rotations. As infected stubble is able to produce ascospores at an epidemic-inducing level for up to 2 years, it suggests that a single canola break might not be enough to reduce the risk of STB or YLS.

It is not known if the differences in ascospore release numbers between resistance ratings, although not significant, has an influence on epidemic severity (further experiments are currently testing this). What can be said, is that regardless of the resistance rating, the number of ascospores released from just 5 tillers for both *Z. tritici* and *P. tritici-repentis* are at a level that can initiate an epidemic up to 2 years later. Remembering that the number of ascospores counted were from 5 tillers only, once that is multiplied out over a square metre, hectare or paddock scale, the number of ascospores produced is at a level that can infect crops locally and regionally.

The distinction needs to be made between managing disease in the current wheat crop to minimise yield loss and inoculum risk from the stubble in subsequent seasons. Even though the number of ascospores released from the stubble does not significantly change with resistance rating, variety choice remains critical to managing STB and YLS within the current season. The NVT ratings show that a more resistant variety develops less disease compared with a more susceptible variety. Picking a variety with a higher resistance level will protect yield in the presence of disease, while reducing the number of fungicide sprays required which, in turn, reduces machinery, labour and input costs. Minimising fungicide use also reduces the risk of fungicide resistance developing within both on-target and off-target fungal pathogen populations.

Harvest cut height can have a big influence on the amount of standing stubble material left in the paddock for *Z. tritici* inoculum production. In turn, it also influences the number of ascospores released from the stubble in the following season. Lowering the harvest cut height, reduces the amount of inoculum left on the standing stubble. However, the excess material that is put through the harvester cannot be left in the paddock otherwise, the inoculum from the standing stubble is only relocated to the ground maintaining the same inoculum levels within the paddock. To achieve a net reduction in inoculum, the excess material from the lower cut height must be removed from the paddock. This can be done by bailing the straw or burning (narrow windrow or blanket burn). Some methods are less labour intensive than others, however the cost benefit risks of each must be considered before being undertaken.

Summary

Components of the research discussed above can be implemented into an integrated disease management plan to control STB and YLS. Acknowledging the risk, and duration of the risk i.e. up to 2 years, that any STB or YLS infected stubble can have on proceeding cereal crops can guide crop rotation decisions, or if growing wheat on wheat, allow a plan to be implemented that can appropriately manage the risk of these diseases. Variety choice, stubble cut height and stubble removal can all be implemented to reduce yield loss and inoculum levels of STB and YLS.

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Author contribution statement

Dr Andrew Milgate conceived of the study, coordinated its design and execution and analysed the data. Tony Goldthorpe and Merrin Spackman conducted the experiments. Brad Baxter and Dr Andrew Milgate wrote the manuscript.

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Resistance to phosphine in stored grain insects from farm storages in south-eastern Australia: 2021

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Key findings

- Approximately 3% of all stored grain insects collected had strong resistance to phosphine – a marked reduction from 18% in 2016.
- Improved hygiene is the probable reason for the observed reduction in resistance.
- Rusty grain beetle resistance remains the most serious issue as it is not controlled by current label rates.

Keywords resistance, stored grain, insects, phosphine, rusty grain beetle, hygiene

Introduction

Most Australian grain markets demand that all stored grain is free of live insects. Currently, there are limited options available for controlling insect pests and all require sealed, gas-tight storages, which are limited on some farms.

Phosphine is the most commonly used fumigant with over 80% of stored grain treated with this product. Phosphine is cheap, considered to be residue-free (meaning it is accepted by most markets), effective at controlling all life stages of all major stored grain pests and does not require a licensed fumigator. However, over-reliance on this product has led to resistance developing in all major stored grain pests.

There are 2 levels of resistance to phosphine: weak and strong. The strengths of these differ with insect species. Currently, phosphine label rates are sufficient to control all life stages of strongly resistant pests of all the major pest species except the rusty grain beetle (RGB – *Cryptolestes ferrugineus*). Our team first detected strong resistance in this species in 2006. It primarily evolved through repeated fumigations in non-gas-tight storages. Given that weak resistance is currently found in virtually all stored grain beetle populations, this study concentrated on detecting strong resistance.

This project is part of a national study that has been conducted for over 20 years. The aims of these projects are to monitor and detect strong resistance to phosphine in the 5 major stored grain beetle pests as well as record all details that might have led to any development of resistance. The objective is to control these outbreaks, develop a phosphine resistance management strategy and consequently prolong the life of phosphine as an effective fumigant.

This paper concentrates on the results from south-eastern Australia for 2021 and relates this information to data from the past decade in order to provide an insight into the future of phosphine resistance.

Methodology

This study focuses on strong resistance to phosphine in the 5 major stored grain beetle pests of south-eastern Australia:

1. lesser grain borer (LGB – *Rhyzopertha dominica*)
2. rice weevil (RW – *Sitophilus oryzae*)
3. flour beetle (FB – *Tribolium castaneum*)
4. saw-toothed grain beetle (SGB – *Oryzaephilus surinamensis*)

5. rusty grain beetle (RGB – *Cryptolestes ferrugineus*).

Stored grain insects were collected from randomly selected farm storages throughout the grain-growing regions of southern NSW (south of Dubbo), Victoria and South Australia. In addition, a small number of growers submitted samples. Farms were selected by driving around a district and calling in when silos were observed. Permission was obtained before sampling and insect surveys were from January 2021 to March 2022. However, due to the time taken to culture the insects to provide sufficient numbers required for the resistance bioassays, the majority of these results are from insects collected from grain harvested in and before 2020.

To check for insects, approximately 1–2 kg of grain was extracted from the base of a silo, sieved and any live insects transferred to a plastic jar along with some untreated grain. Information was recorded on the type of storage, how long the grain had been stored and any chemical treatments applied to the grain. The insects were then transported to the entomology laboratory at Wagga Wagga Agricultural Institute (WWAI) where they were separated into species, provided with unique identifier numbers and cultured on an appropriate feed source. Populations were considered separate if they were sourced from different storages (e.g. different silos). Consequently, one site could have multiple populations.

Once sufficient numbers were cultured, phosphine bioassays were conducted by placing 50 individuals in a plastic cup with air holes within a desiccator. A known discriminating dose of phosphine gas, generated from phosphine tablets, was then injected into the sealed desiccator. Replicates, reference strains and controls (desiccators without any gas added) were included to ensure fidelity of results. After the specified gas exposure duration, insects were assessed as alive or dead. A population was defined as strongly resistant if any insect survived the high dose. Where possible, survivors were cultured and the population re-assessed to confirm the results.

Results

Species composition

During 2021, a total of 402 insect populations were collected from 139 farms throughout south-eastern Australia (51 NSW, 42 Vic, 46 SA) (Figure 1). In addition, there were a further 125 farms (53 NSW, 48 Vic, 24 SA) where no insects were found. The 2 main species collected were FB and LGB, comprising 32.8% and 28.9% of the samples, respectively. Species composition was relatively similar across the 3 states, with no association between state and species collected (Chi-square: P = 0.09, DF = 8) (Figure 2).

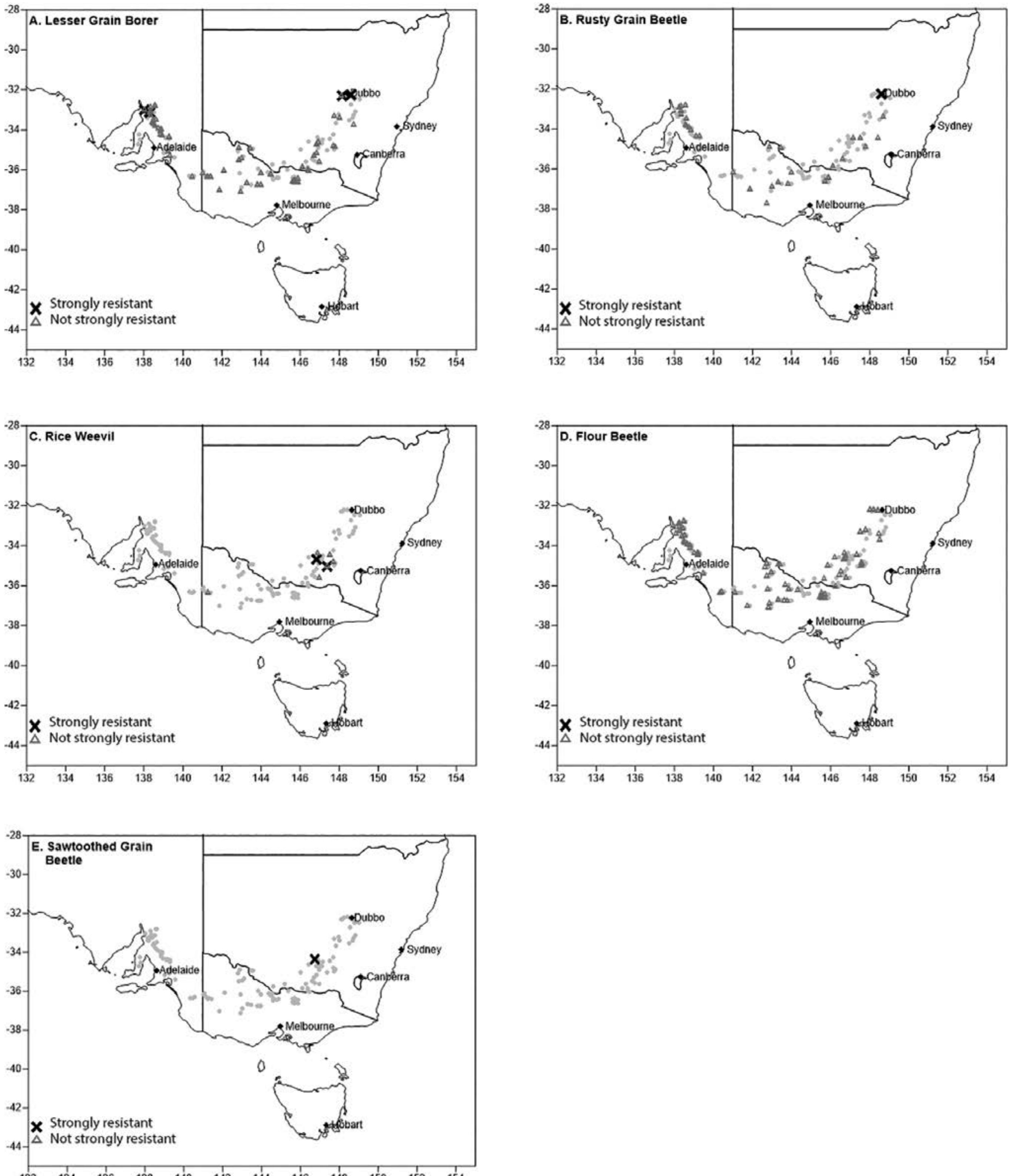

Figure 1 Locations of sampling sites (grey dots) and sites of strong resistance to phosphine in stored grain species (black crosses) from 2021.

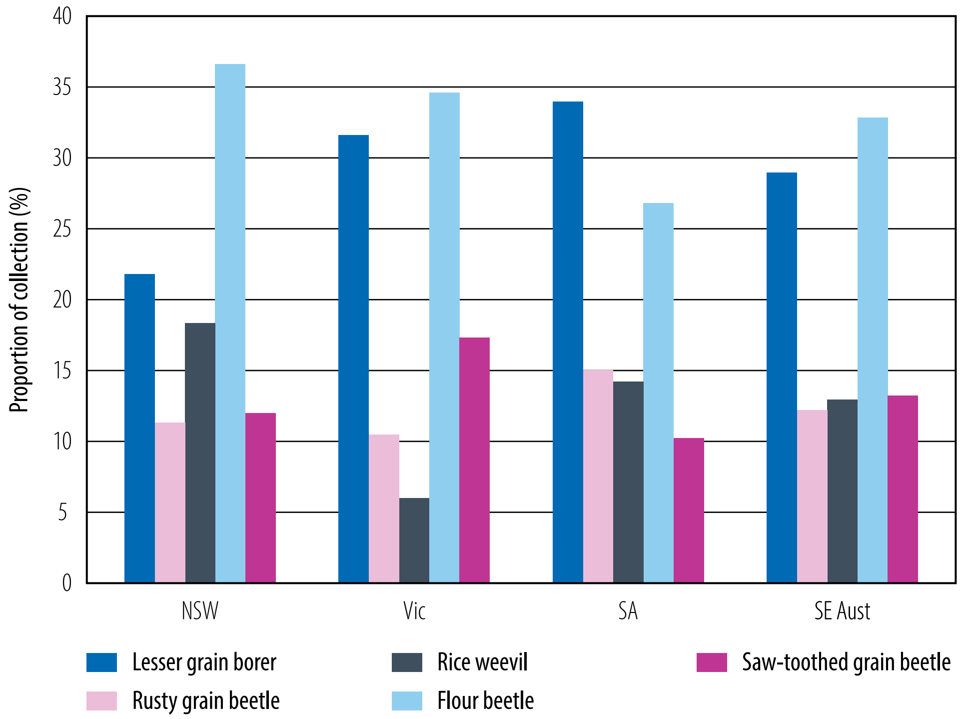

Figure 2 Proportions of stored grain beetle pests sampled from farms throughout south-eastern Australia in 2021.

Phosphine resistance

When all species were combined, 3.2 % of the 251 populations tested were found to have strong resistance to phosphine (Figure 3). This is a significant drop from both 2011 and 2016 when resistance levels were 7.8% (590 populations) and 18.3% (437 populations), respectively. The highest levels were found in NSW (7.7% of 78 populations), followed by South Australia (2.6% of 76 populations). No strong resistance was found in stored grain insects collected from Victoria during 2021.

Looking at individual species, RW and LGB had the highest proportions of strong resistance in 2021 with 25.0% and 5.3%, respectively, followed by RGB (3.1%) and SGB (2.5%). It should be noted that only 8 populations of RW were collected. No strong resistance was detected in FB populations. This contrasts with 2016 when 27% of populations were found to be strongly resistant to phosphine.

The proportion of strong resistance to phosphine throughout south-eastern Australia has decreased since 2016 in all species. Easing drought conditions, high grain prices and the prospect of a bumper harvest resulted in old, stockpiled grain being removed, and silos cleaned and treated before the 2020 harvest. Consequently, potentially resistant insects due to repeated fumigations were removed. Conditions in many parts of south-eastern Australia were very dry before 2016 and a large amount of grain was held on farm for supplemental stock feed. Long-term grain storage often results in an increase in stored grain insect pests. Multiple fumigations on the same parcels of grain and insect populations, if not performed to standard, increases the chance of strong resistance developing. However, by the 2020 harvest, conditions had improved, and a good harvest was expected. This allowed the silos to be completely emptied, cleaned, and treated. Consequently, any insects, resistant or otherwise were removed.

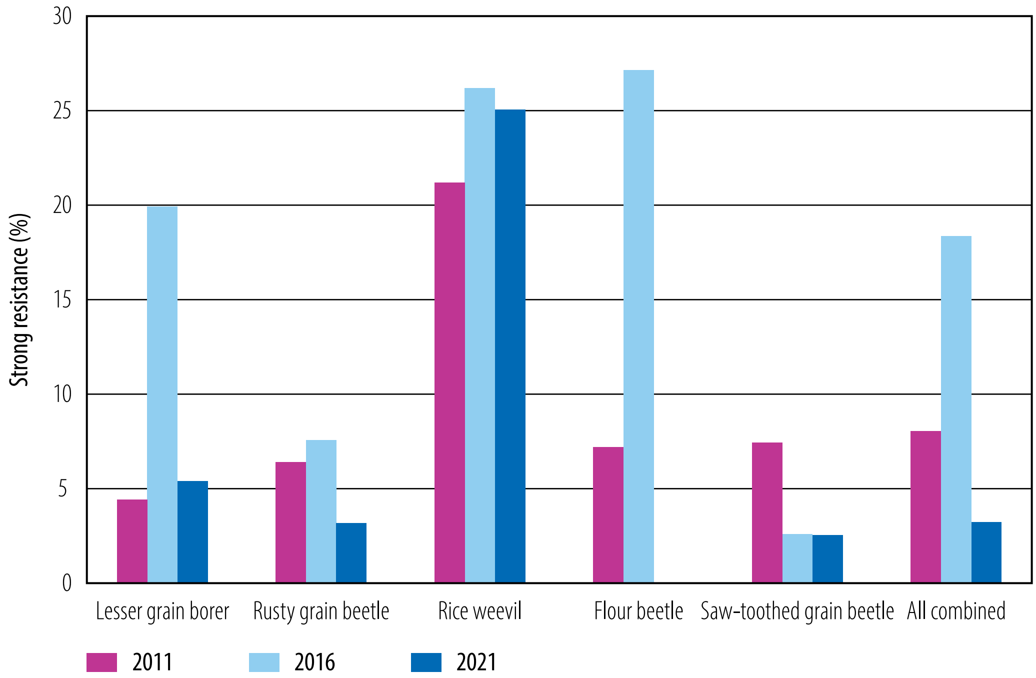

Figure 3 Combined levels of strong resistance to phosphine found in stored grain beetle pests sampled from farms throughout south-eastern Australia in the past decade.

Summary

The abundance of strong resistance to phosphine in stored grain beetle pests on farms has decreased substantially since 2016, most probably due to improved hygiene on farms in anticipation of bumper harvests. The most common species detected with strong resistance to phosphine was LGB. There were no detections of strong resistance in FB populations collected from farms during 2021. The highest number of strongly resistant insect populations were detected in NSW while none were found in Victoria.

If performed correctly, current fumigation label rates will control even strongly resistant populations of all stored grain beetle pests except RGB. Only one population of strongly resistant RGB was detected in on-farm storages in 2021. It is important that strong resistance, particularly in this species is controlled. If left unchecked, live insects might be detected in grain deliveries and subsequently rejected at delivery points.

Acknowledgements

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We sincerely thank all the growers for allowing us access to their grain silos.

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Seed viability of feathertop Rhodes grass (*Chloris virgata* Sw.) affected by sheep rumen digestion

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Key findings

- Feathertop Rhodes grass seed viability was reduced by more than 99% after feeding through sheep.
- A low level of viable seeds (<1%) can still be detected 12 days after feeding, therefore, if sheep graze feathertop Rhodes grass, they should be quarantined for at least 8 days in order to prevent seed spread.

Keywords feathertop, Rhodes grass, digestion, sheep, weeds, resistance

Introduction

Feathertop Rhodes grass is a major weed in both cropping and non-cropping situations in Australia. This annual species is very difficult to control, and no single weed management option will provide adequate control. Currently feathertop Rhodes grass control relies heavily on a few registered herbicides, particularly those with glyphosate and acetyl-CoA carboxylase inhibitors, resulting in the rapid evolution of resistance to these key agrochemicals (Heap 2022). An integrated approach is therefore required to effectively manage this weed.

Annual weed grasses are often highly palatable to grazing ruminants (Marten and Anderson 1975). Sheep can be used to directly consume and control weeds, not only during fallow years but also during fallow periods before planting and after harvest, thereby replacing herbicide dependency. However, weeds and weed seeds present at the time consumed by sheep and from harvest are preserved in silage with the forage and it is often assumed that this renders most of these weed seeds non-viable (Kaiser et al. 2004). However, there is no reported data on feathertop Rhodes seeds survival after passing through the digestive tract of sheep. This research aimed to determine the percentage of viable seed recovered after passing through the digestive tract of sheep.

Site details

Location

Wagga Wagga Agricultural Institute, Wagga Wagga

Time of experimentation

November 2020 and March 2021

Seed population and number sheep

One feathertop Rhodes grass population MUTT 04/20 (146° 34′ 201″ E, 35° 07′ 606″ S) and 8 sheep.

Sheep feeding and faeces collection

Eight sheep were individually penned and fed a diet consisting of lucerne and oaten chaff (1:1). The sheep were fed each morning a standard diet at 800 g/day, mixed with 40 g of feathertop Rhodes grass seeds (about 135,800 seeds). After feathertop Rhodes grass seed was introduced into the diet, total faeces were collected daily from day 1 to day 12 to determine the time taken from ingestion to complete excretion of the seed. Faecal collection for each day occurred 24 hours after feeding, hence faeces for day 1 were collected before feeding on day 2 etc.

Faeces spread on germination tray

To determine the percentages of seed viability in the faeces, each faeces sample was weighed and separated into 3 sub-samples. The first sub-sample (approximately 260 g) was used to determine seed viability in glasshouse conditions. The second sub-sample was air-dried and kept in a cool room for further testing to confirm the results. The third sub-sample was used for digestibility testing (not reported here).

To determine the percentages of seed viability in the faeces, the first sub-sample was evenly spread onto a plastic seedling tray (32 cm × 28 cm × 6 cm) that was filled with a field soil (loamy soil). The faeces were gently rubbed and lightly mixed with the surface soil. The trays were kept moist and monitored for 21 days. The trays were maintained under glasshouse conditions and irrigated as required.

The experiment was repeated in March 2021 with the second sub-sample to validate the results obtained in 2020. An additional control treatment was included in 2021 where 300 feathertop Rhodes grass seeds were spread on a seedling tray under the same glasshouse conditions used in 2020.

Germination and viability evaluation

Total emerged seedlings were counted to estimate seed viability and the speed with which feathertop Rhodes grass seed passed through the sheep gut. It is not possible to extract the seeds from the faeces through sieving or washing due to the tiny seed size (0.39 mg/100 seeds).

Experiment design and data analysis

A completely randomised design was used, with 8 replications. The significant differences among days after faeces collection were identified by Tukey's HSD (honest significant difference) at $p<0.05$.

Results

The average amount of fresh faeces from 8 sheep from day 1 to day 12 is presented in Table 1. Fresh faeces weight ranged from 695.25 g to 968 g with an average of 789 g for day 1 to day 12.

Table 1 Average fresh faeces (g) collected, number of seedlings emerged/tray and cumulative emergence (%) from day 1 to day 12.

Day after feeding	Faeces (g)	2020		2021	
		Average seedlings emerged per tray	Cumulative emergence (%)	Average seedlings emerged per tray	Cumulative emergence (%)
1	695.25 (±74.9)	8.7 (±1.3)	23.0	3.4 (±1.2)	34.6
2	671.25 (±77.3)	9.0 (±2.6)	47.0	1.7 (±0.9)	51.9
3	727.50 (±98.5)	4.3 (±1.3)	58.0	1.0 (±0.7)	62.1
4	791.87 (±95.6)	3.3 (±1.6)	67.0	0.7 (±0.7)	69.2
5	851.37 (±96.5)	5.0 (±0.9)	80.0	0.4 (±0.3)	73.2
6	757.25 (±93.2)	1.2 (±1.1)	83.0	0.4 (±0.4)	77.2
7	759.38 (±73.3)	2.0 (±0.3)	88.0	0.3 (±0.4)	80.2
8	968.13 (±69.7)	0.7 (±0.5)	90.0	0.0 (±0.0)	80.2
9	789.25 (±70.9)	2.6 (±1.4)	97.0	0.5 (±0.5)	85.3
10	858.0 (±94.8)	0.6 (±0.6)	99.0	0.5 (±0.4	90.4
11	845.63 (±66.7)	0.1 (±0.1)	99.3	0.3 (±0.1)	93.4
12	757.75 (±37.3)	0.5 (±0.3)	100	0.6 (±0.3)	100

Note: ± = standard error

In both years, most seedling emergence (58–62%) occurred from the faeces collected during the first 3 days after seed intake (Table 1). It was observed that there was still limited seedling emergence from the 12-day faeces, being less than 1% in 2020 and 7% in 2021. On average, the total number of emerged seedlings from day 1 to day 12 was 38.0 in 2020 and 9.8 in 2021, which is estimated at only 0.08% and 0.02% of the seeds fed in 2020 and 2021, respectively.

In comparison, 53.4% of the total control seeds germinated in the trays under the same conditions. This shows that sheep rendered more than 99.9% of feathertop Rhodes grass seeds unviable after passing through the digestive system.

Seedling emergence in 2020 was significantly ($r = 0.82$, $p = 0.0012$) correlated with seedling emergence in 2021 (Figure 1) indicating consistent results across both experiments.

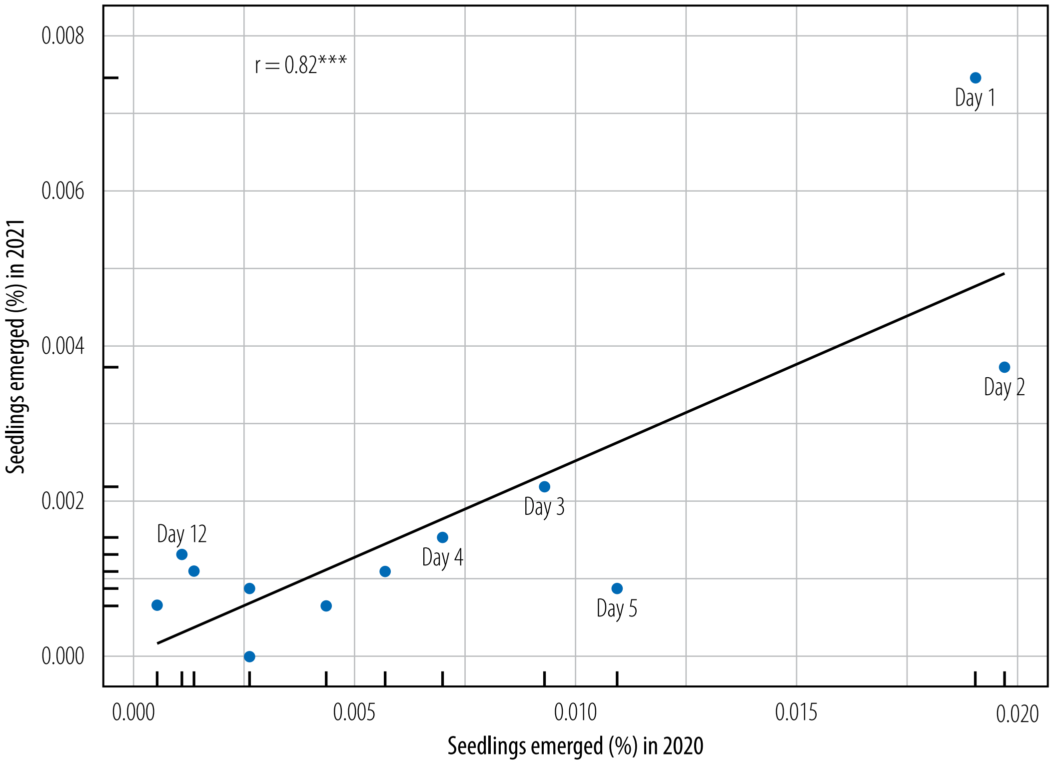

Figure 1 Correlation between seedlings emerged (%) in the sheep feeding experiment in 2020 and 2021 at different days after faeces collection.

Summary

This two-year study suggested that feathertop Rhodes grass seed viability can be reduced by feeding to sheep. In 2020, which had higher numbers of excreted viable seed, there was 80% collection during days one to 5. Seed viability percentages after ingestion ranged from 0.022% to 0.084%. Feathertop Rhodes grass seed viability was reduced by more than 99.9% after feeding through sheep, indicating the spread of feathertop Rhodes grass seeds through sheep tracts is minimal. However, a low level of germinable seeds (<10%) can still be detected 12 days after feeding.

Weeds

Practical implications

Sheep grazing should only be performed before seed head emergence to reduce the risk of potential spread. If sheep are suspected of having fed on mature plants, they ideally should be quarantined for a week to allow more than 80% of seeds to be excreted.

Effective grazing before seed head emergence provides an alternative to herbicides thereby reducing selection pressure for herbicide resistance. It can also buy time for effective control. For example, advanced weeds under moisture stress are often less responsive to herbicide application. Sheep grazing the stressed plants could allow herbicide application at a later stage when spraying conditions are more ideal for maximum control efficacy.

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Rice variety V071⁽ᶲ⁾ compared with Reiziq⁽ᶲ⁾

Brian Dunn and Tina Dunn

NSW DPI, Yanco

Key findings

- Three seasons of research have provided confidence that V071⁽ᶲ⁾ is a superior rice variety to Reiziq⁽ᶲ⁾ in all agronomic attributes.
- The V071⁽ᶲ⁾ grain yield was higher than Reiziq⁽ᶲ⁾ in all experiments by an average of 1.43 t/ha.
- V071⁽ᶲ⁾ development does not slow during periods of low temperatures like Reiziq⁽ᶲ⁾, which is very beneficial in cool seasons.
- V071⁽ᶲ⁾ has strong emergence and establishment vigour like Reiziq⁽ᶲ⁾, and a higher tolerance to grain shattering than Reiziq⁽ᶲ⁾.
- Provided V071⁽ᶲ⁾ meets market quality requirements, it is showing potential to be a welcome replacement for Reiziq⁽ᶲ⁾, the current industry standard bold medium-grain rice variety for the past 18 years.

Keywords rice, V071, Reiziq, variety

Introduction

The standard semi-dwarf bold medium-grain rice variety Reiziq⁽ᶲ⁾ accounted for over 70% of rice production in southern New South Wales in the 2021 season. Reiziq⁽ᶲ⁾ was released in 2004 and, due to its large grain size, still has a strong presence in the Middle East, Australian and New Zealand markets. Although it can produce high yields, cold during the reproductive stage often reduces grain yield below the variety's potential.

V071⁽ᶲ⁾ is a variety bred by the Australian Rice Partnership, a NSW DPI, SunRice and AgriFutures Australia joint venture. V071⁽ᶲ⁾ is a semi-dwarf, bold medium-grain rice variety with high yield potential and is likely to replace Reiziq⁽ᶲ⁾ provided grain quality attributes satisfy the markets.

Site details

Fifteen experiments were established over 3 seasons across the Murrumbidgee Irrigation Area, Coleambally Irrigation Area and Murray Valley rice growing regions of southern NSW. The experiments were established in commercial grower fields covering aerial, dry broadcast, drill and delayed permanent water (DPW) sowing and irrigation methods.

Experiments

All experiments included 3 replications with plots generally 2.4 m wide by 12 m long. All plots were hand sampled at panicle initiation (PI) and harvest. Grain yield was assessed in most experiments by small plot harvester. Tiller and panicle samples were collected to determine yield components together with extensive measurement of growth stage timing. Air and water temperature were measured at each site.

Rice varieties

The varieties Reiziq⁽ᶲ⁾ and V071⁽ᶲ⁾ were grown in all experiments with varieties Sherpa⁽ᶲ⁾, Viand⁽ᶲ⁾ and Opus also included for direct comparison in many experiments.

Rice

Nitrogen treatments

All experiments included several nitrogen (N) treatments with a range of permanent water (PW) N rates to suit each specific field and splits with PI applied N to determine each variety's optimal N rate and timing requirements.

The grain yield results presented for each experiment (Table 1) are an average of N rates best suited for each variety at that site.

Results

Grain yield

V071$^{\phi}$ produced a higher grain yield than Reiziq$^{\phi}$ in all 15 experiments conducted over the 3 seasons (Table 1). The V071$^{\phi}$grain yield was between 0.40 t/ha and 2.57 t/ha higher than Reiziq$^{\phi}$, averaging 1.43 t/ha.

High grain yield can often result in increased crop lodging, although this was not evident in any of the experiments. The increased V071$^{\phi}$ grain yield has not resulted in a higher susceptibility to lodging compared with Reiziq$^{\phi}$ at the equivalent N rates.

Table 1 Grain yield (t/ha @ 14% moisture) of Reiziq$^{\phi}$ and V071$^{\phi}$ from 15 variety × nitrogen rice experiments conducted in commercial fields over 3 seasons covering the southern NSW rice growing regions.

Season	Location	Sowing method	Grain yield (t/ha)		Yield difference (t/ha)
			Reiziq	V071	
2019/20	Coleambally	Drill	11.70	13.32	1.62
	Jerilderie	Drill	11.71	13.66	1.95
	Logie Brae	Drill	10.55	12.87	2.31
2020/21	Yenda	Drill	14.26	14.60	0.34
	Benerembah	Dry broadcast	11.26	11.66	0.40
	Leeton	DPW	13.52	13.92	0.40
	Mayrung	Aerial	11.91	14.48	2.57
	Jerilderie	DPW	12.39	14.05	1.66
2021/22	Yenda	Drill	14.00	15.29	1.29
	Benerembah	Dry broadcast	12.58	14.19	1.61
	Coleambally	Drill	13.27	14.80	1.52
	Bunnaloo	Drill	12.56	14.12	1.56
	Moulamein	Drill	13.20	14.78	1.58
	Mayrung	Aerial	14.50	15.28	0.78
	Jerilderie	DPW	12.79	14.60	1.81
Average			12.68	14.11	1.43

DPW = delayed permanent water.

Growth duration

Rice growth duration is influenced by sowing/irrigation method, temperature and sowing time. In a season with average temperatures, V071$^{\phi}$ and Reiziq$^{\phi}$ take a similar number of days to reach flowering and maturity, but in seasons with periods of cool temperatures during the vegetative period, V071$^{\phi}$ is quicker as low temperatures do not delay the phenological development as occurs with Reiziq$^{\phi}$.

It can be seen in Yenda 2020/21 and 2021/22 and Bunnaloo 2021/22 experiments, which were sown early and experienced low temperatures during the vegetative period, that the Reiziq$^{\phi}$ days to flowering were delayed between 6 and 10 days compared with V071$^{\phi}$ (Table 2).

Table 2 Days to mid-flowering and 22% moisture for Reiziq$^{\Phi}$ and V071$^{\Phi}$ at commercial nitrogen rates*.

Season	Location	Sowing method	Sow/first flush date	Days to flower		Days to 22% moisture	
				Reiziq	V071	Reiziq	V071
2019/20	Coleambally	Drill	19 Oct 19	112	112	178	176
	Jerilderie	Drill	21 Oct 19	114	118	178	175
	Logie Brae	Drill	30 Oct 19	112	110	176	166
2020/21	Yenda	Drill	9 Oct 20	110	104	169	165
	Benerembah	Dry broadcast	23 Oct 20	103	103	156	156
	Leeton	DPW	14 Oct 20	118	118	176	177
	Mayrung	Aerial	21 Oct 20	113	111	172	167
	Jerilderie	DPW	21 Oct 20	119	117	183	173
2021/22	Yenda	Drill	30 Sep 21	127	118	181	174
	Benerembah	Dry broadcast	28 Oct 21	106	102	150	148
	Coleambally	Drill	9 Nov 21	106	110	167	166
	Bunnaloo	Drill	11 Oct 21	128	118	170	166
	Moulamein	Drill	14 Oct 21	117	117	-	-
	Mayrung	Aerial	18 Oct 21	112	110	173	165
	Jerilderie	DPW	14 Oct 21	127	123	187	179
Average				115	113	173	168

* Data from 15 experiments conducted in commercial fields over 3 seasons covering the rice growing regions and sowing/irrigation methods.

Summary

Three seasons of research across all regions and sowing methods have provided us with confidence that V071$^{\Phi}$ has superior agronomical attributes compared with Reiziq$^{\Phi}$.

The V071$^{\Phi}$ grain yield was higher than Reiziq$^{\Phi}$ in all experiments and this advantage was maintained when grown using the water saving method, DPW.

V071$^{\Phi}$ has higher tolerance to low temperatures during the reproductive period than Reiziq$^{\Phi}$ (C. Proud, 2022 pers comm) which helps it maintain high grain yields over a larger range of seasonal temperatures. The phenological development of V071$^{\Phi}$ does not slow during periods of low temperatures like Reiziq$^{\Phi}$, which is also very beneficial in cool seasons.

Other research we have conducted over the last 3 seasons shows that V071$^{\Phi}$ has strong emergence and establishment vigour, similar to Reiziq$^{\Phi}$, which is the best of all current commercial varieties. V071$^{\Phi}$ has a higher tolerance to grain shattering than Reiziq$^{\Phi}$, an important feature during harvest (Dunn and Dunn 2021).

Provided V071$^{\Phi}$ meets the quality attribute requirements of the markets V071$^{\Phi}$ is showing potential to be a welcome replacement for Reiziq$^{\Phi}$ which has been the major industry variety for the last 18 years.

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Proud C (13 July 2022) University of Queensland, personal communication.

Acknowledgements

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Effect of panicle initiation nitrogen timing on rice grain yield

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Key findings

- At all crop nitrogen levels applying nitrogen at panicle initiation (PI) increased grain yield above where no PI nitrogen was applied.
- When crop nitrogen levels are deficient applying nitrogen close to PI increased grain yield above later applications.
- The timing of PI topdressing nitrogen application had no effect on grain yield when crop nitrogen levels were adequate.

Keywords panicle initiation, nitrogen, rice, yield

Introduction

Rice growers have no reliable method to determine how much soil nitrogen (N) will be available to a rice crop before sowing. They rely on their knowledge of cropping history, soil organic N levels, Primefacts (Rice variety guide, https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/summer-crops/rice-development-guides/rice-variety-guide-202122) and agronomists to guide their decision on how much N to apply before permanent water (PW).

Panicle initiation is the second-most efficient time to apply N to a rice crop. As PI is a defined growth stage, crop N level can be measured, and N topdressing recommendations based on experimental results provided to growers and agronomists. The recommended PI topdressing window is from PI to 10–12 days after PI. By applying N at this time, the crop still has the ability to use the N to increase grain yield.

In 2022, many rainfall events occurred around PI that made the aerial application of N very difficult. With wet/unusable airstrips and a back log of jobs, the question was asked 'how late is too late to apply N after PI?'.

Site details

An experiment was established at Rice Research Australia Pty Ltd (RRAPL), Coree, 20 km west of Jerilderie on a self-mulching medium clay soil.

Treatments

Rice variety

The variety grown was V071⊕, which is a semi-dwarf, bold, medium-grain rice variety with high yield potential. It has superior grain yield and cold tolerance to Reiziq⊕, the most common rice variety currently grown in southern NSW.

Sowing rates

The experiment was sown with a disc drill seeder at 20 cm row spacing with a 140 kg/ha sowing rate. The first flush was on 29 October 2021 and it received 3 flush irrigations before PW was applied on 7 December 2021. Weed control was managed as per commercial recommendations.

Nitrogen treatments

The experiment had 2 replications with N treatments applied as urea at multiple timings:

1. Main plots received N at rates of 0, 60 and 120 kg N/ha applied onto the dry soil before PW.
2. At PI, each main plot was split with N applied at timings of 1, 8 and 15 days after PI. Nitrogen rates of 0, 60 and 120 kg N/ha were applied each time to produce sub-plots 3 m by 2 m in size.

Rice

Results

Permanent water nitrogen (PW N)

The addition of N applied before PW increased grain yield from 9.01 t/ha to 11.40 t/ha and 12.89 t/ha for the 60 and 120 kg N/ha rates respectively (Table 1). The N applied at PW also increased total dry matter (TDM) and the number of tillers at harvest, but the latter was not statistically significant.

Plant height increased significantly from 78 cm to 84 cm and 87 cm for the 0, 60 and 120 PW N treatments respectively, while harvest index was significantly lower for the 120 PW N treatment than the other 2 treatments (Table 1).

Table 1 Effect of nitrogen rates applied to pre-permanent water on plant growth and grain yield averaged across all PI N treatments.

PW N (kg/ha)	Plant height (cm)	TDM (g/m^2)	Harvest tillers (No/m^2)	Grain yield (t/ha@14%)	Harvest index
0	78	1420	325	9.01	0.56
60	84	1802	426	11.40	0.56
120	87	2104	490	12.89	0.54
l.s.d. (P<0.05)	3.4	90	n.s.	3.09	0.009

l.s.d. = least significant difference, n.s. = not significant.

Panicle initiation nitrogen (PI N)

Applying N at PI significantly increased grain yield above the zero control regardless of N rate or when applied. When averaged across PW N treatments, there was no significant difference in grain yield between the PI N applications for either the 60 kg N/ha or 120 kg N/ha PI application rates (Table 2).

Total dry matter and plant height were increased by additional N at PI, although not always significantly and the number of tillers at harvest was not changed by N applied at PI (Table 2).

Table 2 Effect of PI nitrogen rates and application timing on plant growth and grain yield averaged across PW N treatments.

PI N (kg/ha)	Number of days after PI	Plant height (cm)	TDM (g/m^2)	Harvest tillers (No/m^2)	Grain yield (t/ha@14%)	Harvest index
0	0	80	1652	415	10.17	0.55
60	1	82	1779	415	11.09	0.55
	8	83	1762	407	11.00	0.55
	15	83	1718	393	10.90	0.56
120	1	82	1879	444	11.75	0.56
	8	86	1855	417	11.46	0.55
	15	82	1782	404	11.32	0.56
l.s.d. (P<0.05)		2.4	90.1	n.s.	0.57	0.009

l.s.d. = least significant difference, n.s. = no significant difference.

The grain yield interaction between PW N and PI N was not statistically different, but distinct trends can be seen particularly when no N was applied before PW (Figure 1). In the treatment with no PW applied N, grain yield was highest when the PI N application was closest to PI and declined the later the N was applied (Figure 1). This same trend was not apparent when 60 kg N/ha or 120 kg N/ha was applied at PW.

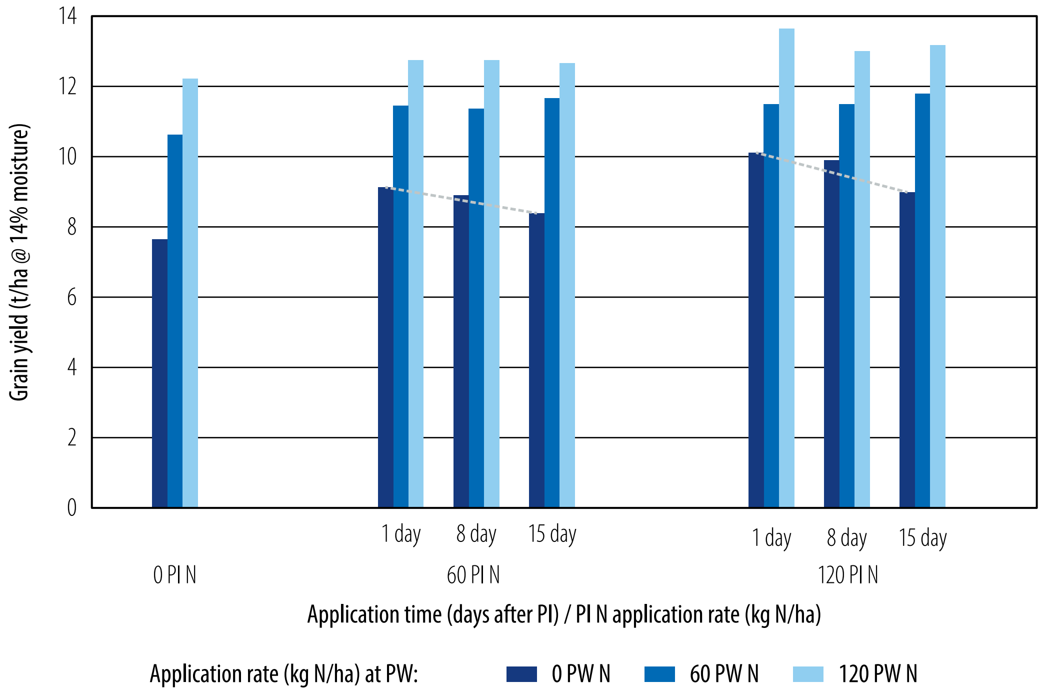

Figure 1 Effect of PI nitrogen application timing on grain yield of rice with 0, 60 and 120 kg N/ha applied at PW.

Nitrogen applied before PW produces a much higher grain yield than N applied at PI. However, with no reliable method to determine how much soil N will be available to a rice crop before sowing, N topdressing at PI is often required to reach optimum yield.

Previous research has shown that it is too late to topdress crops once the majority of panicles are more than 50 mm long. Further, the yield response and economic return on N application declines with plant age (Ward 2021), and by heading (approximately 30 days after PI), it is completely ineffective.

Summary

From these preliminary results we can conclude that a rice crop with a low N status requires N topdressing as close to PI as possible. The crop requires more time to use the added N to grow and increase dry matter and yield potential.

This experiment was designed mid way through the 2022 rice season when the question was asked 'how late is too late to apply N after PI?'. Because of this, only 2 replications of the main plots were possible making it difficult to draw significant conclusions from the results. Therefore, further investigation of the effect PI N application timing has is required to fully identify the differences in treatments.

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Acknowledgements

This experiment was part of the 'Agronomy and remote sensing to maximise rice water productivity' project, PRJ-013235, 2021–24, with joint investment from AgriFutures and NSW DPI.

Thank you to Rice Research Australia Pty Ltd and Ben Heaslip for their support with this experiment.

Rice

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Cotton under a future climate

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Key findings

- Preliminary projections for NSW suggest a warmer future climate that would be more suited to growing irrigated cotton if water was not limiting.
- More irrigation water will be needed to realise the potential of the future climate.

Keywords cotton, southern, climate, water, future

Introduction

The Vulnerability Assessment (VA) project is part of the NSW Primary Industries Climate Change Research Strategy (CCRS; https://www.dpi.nsw.gov.au/dpi/climate/about-dpi-climate/climate-change-research-strategy). The project assesses the relative impacts of climate change on 5 industry sectors: Extensive livestock, broadacre cropping, horticulture and viticulture, fisheries, and forestry. Several commodities are assessed in each sector; irrigated cotton is one of the 9 broadacre crops being examined. We chose irrigated cotton as the focus of this paper because it is grown throughout NSW, makes a significant contribution to the value of agricultural production and is likely to be sensitive to changes in climate. Irrigation water is more available in the south of the state and this combined with the release of longer season varieties has led to the increase in the area of cotton grown in southern NSW.

This paper examines the consequences of climate change for the production and water demand of irrigated cotton and compares its performance throughout NSW.

Site details

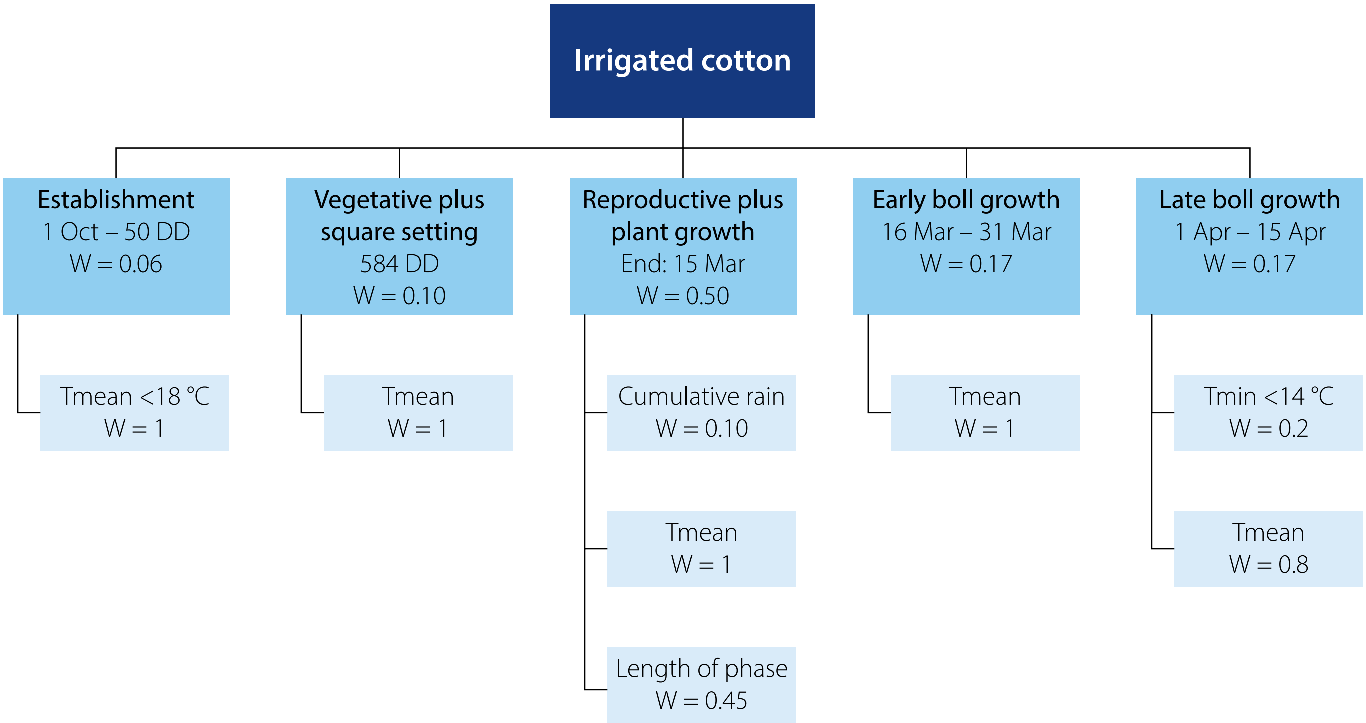
Location

The project assesses the impact of climate change throughout NSW.

Treatments

Multi criteria analysis model

A standard assessment method was applied to all commodities in the VA project so they could be compared. Multi criteria analysis (MCA) (Saaty 1990) was used because it is a decision-making analysis tool that evaluates multiple (conflicting) criteria to reach decisions. It focuses on what is important, is logical and is consistent. A hierarchical MCA model was developed that set out the key climate variables for each phase of irrigated cotton production. The MCA approach used an expert panel, or focus group, to critique the MCA design and to set the variable weightings in the model through a standard analytic hierarchy process (AHP) (Saaty 1990). The final model had 5 phases, fixed planting and harvest dates and a dynamic phenology driven by thermal time (Figure 1).



Note: Five phases and their duration either in degree days (DD) or chronological time are shown. The weight (W) or importance of each phase is indicated. The climate variables driving suitability during each phase are shown below the phase; where more than one variable is considered they are weighted according to their importance.

Figure 1 The MCA model of irrigated cotton.

Water demand

We modelled crop irrigation demand as the difference between effective rainfall and crop evapotranspiration. Thirty percent (30%) of rain falling in the fallow period of 15 April–1 October was carried over to growing season rainfall; 15% during establishment and 15% during vegetative plus square setting. During the growing season, 30% of effective rainfall (75% of total rain) during a phase was added to the rain falling during the subsequent phase.

Water supply

We have not explicitly considered water availability in this analysis, but the consensus is that climate change is expected to decrease irrigation water availability in southern NSW. Twelve NSW regional water strategies (https://water.dpie.nsw.gov.au/plans-and-programs/regional-water-strategies) are addressing this issue, the Lachlan, Murrumbidgee and Murray regional water strategies are well advanced and will be exhibited for community feedback during 2022.

Climate data

The MCA model was run using CSIRO climate change for Australia: Application ready data (CSIRO 2015). An historic baseline period (1981–2010) and future climate (2036–2065) were used. The future climate was predicted using 2 representative concentration pathways (RCPs). The first (RCP 4.5) predicts emissions will decline from 2040, the second (RCP 8.5) assumes emissions continue to rise. The median of 8 global circulation models that represent a range of plausible future climates was used.

Results

Climate suitability

Historically the climate of the western cotton growing region (Bourke) was highly suited to growing cotton, as was the western half of the northern region (Moree and Narrabri). The eastern portion of the northern region and the central valleys were also highly suitable for cotton growing, but the southern

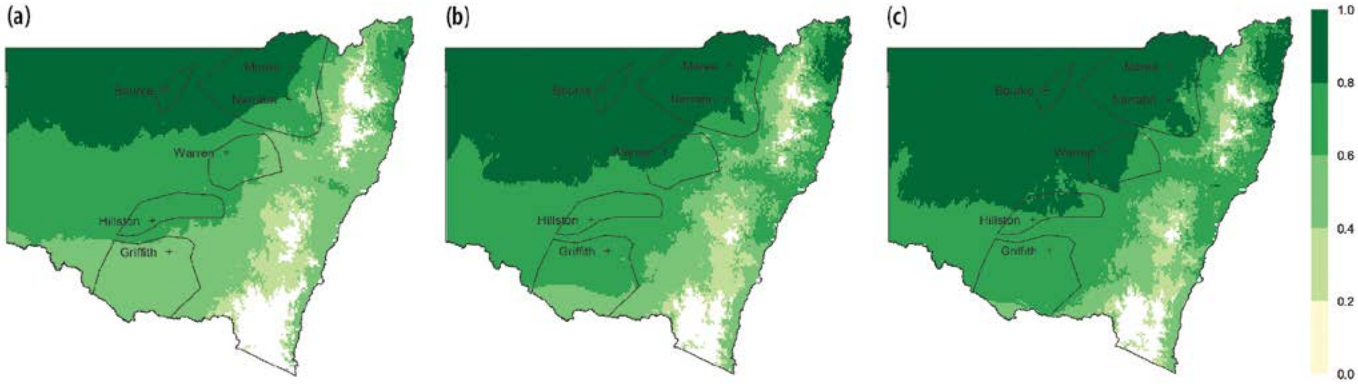


Figure 2 Preliminary maps showing the NSW climate suitability for growing cotton under (a) historic, and (b) RCP 4.5 and (c) RCP 8.5 predicted future climates.

Under both emissions scenarios, the suitability of all regions increased with a greater increase under the RCP 8.5 emissions scenario (figures 2b and 2c).

Each of the 8 global circulation models represents the future climate differently. This will result in a range of suitability scenarios predicted by the MCA model and is known as the uncertainty in our predicted suitability and will vary from place to place. In northern NSW increases in the suitability of the climate for cotton were smaller than in southern NSW (Figure 3). We have high confidence in these projections.

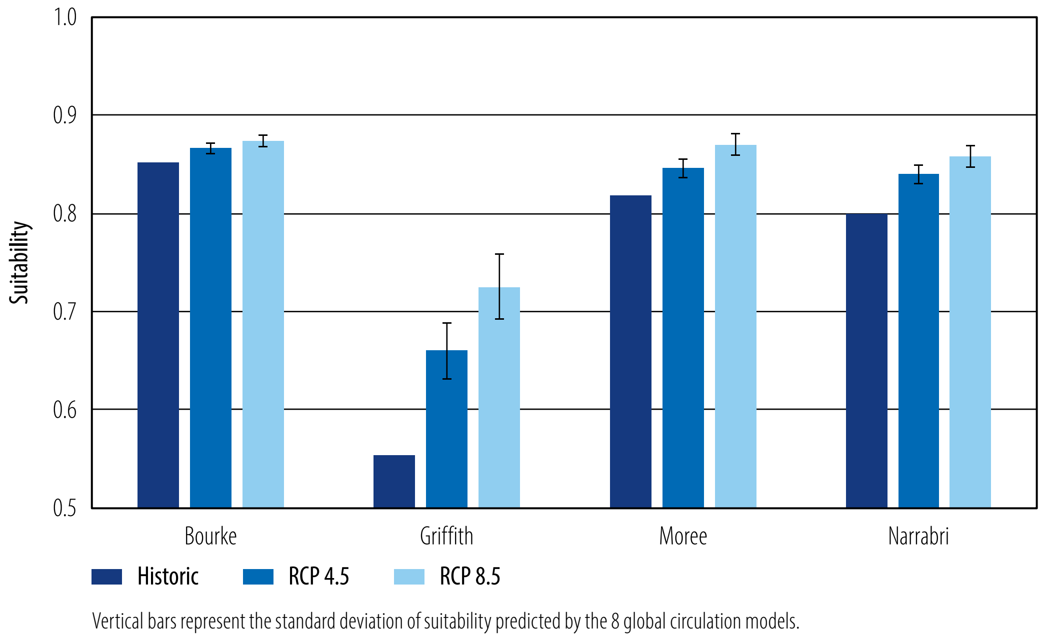
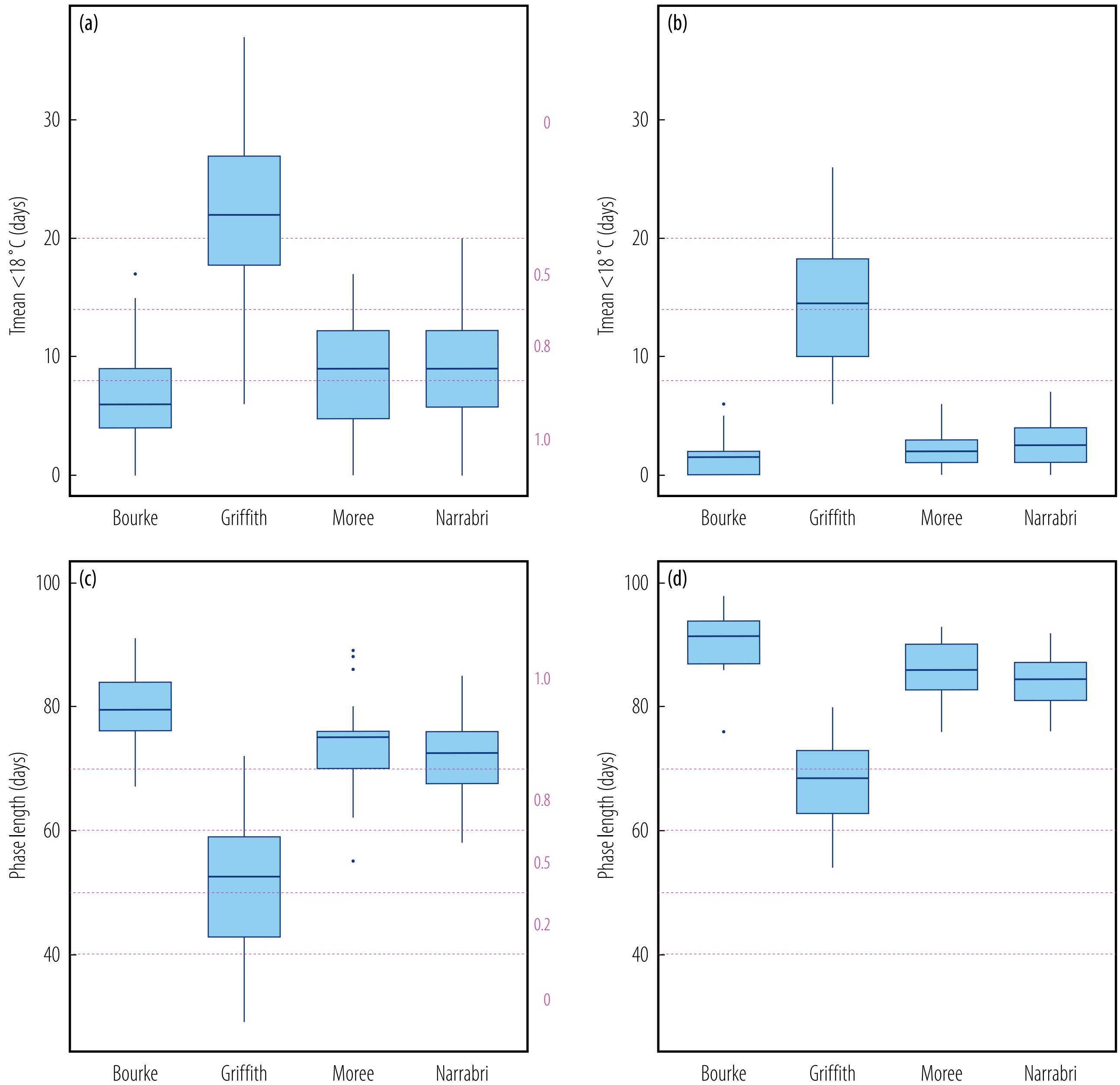


Figure 3 The suitability of the test locations under historic climate and that predicted under RCP 4.5 and RCP 8.5.

Increased temperature and more rapid crop development drive these improvements in suitability under future climates. This leads to earlier emergence due to fewer cold days during establishment and a longer period of reproductive growth when the plants set their yield potential (Figure 4). These changes are greater at Griffith leading to a larger change in suitability (Figure 3).



The pink numbers and dashed lines indicate the suitability classes.

Figure 4 The number of cold days during establishment at 4 key cotton growing locations under, a) historic and b) future climate projected under RCP 8.5; and reproductive phase length under, c) historic and d) future climate projected under RCP 8.5.

Water demand

Water demand increased under both future emissions scenarios (Figure 5). At all 4 test locations the increased water demand under RCP 4.5 was less than 1 ML/ha, but exceeded 1 ML/ha under RCP 8.5. Bourke had the highest water demand and the smallest change while Griffith had the lowest water demand but the greatest change in the future (Figure 5).

The uncertainty in water demand predicted by the 8 global circulation models was quite high at the 4 key cotton growing locations (Figure 6). The uncertainty was greater under RCP 8.5, the high emissions scenario.

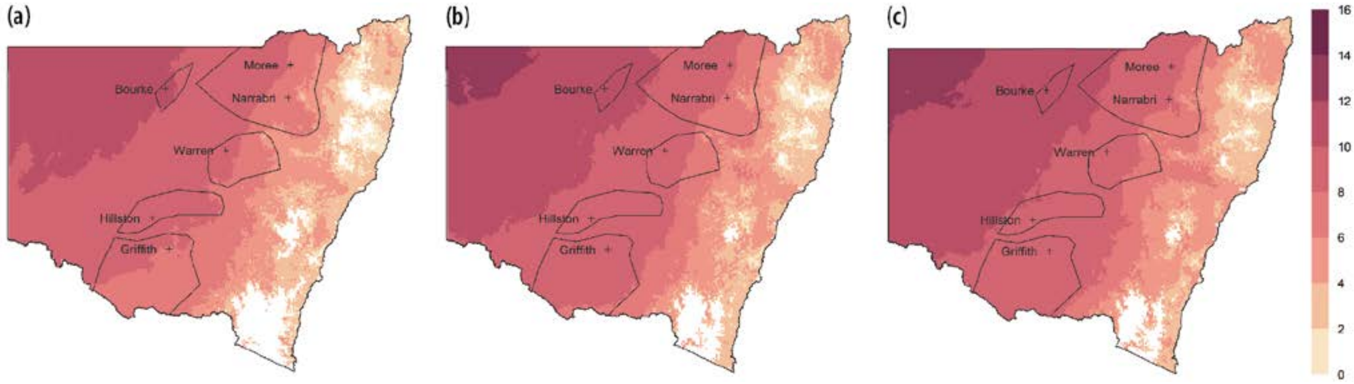
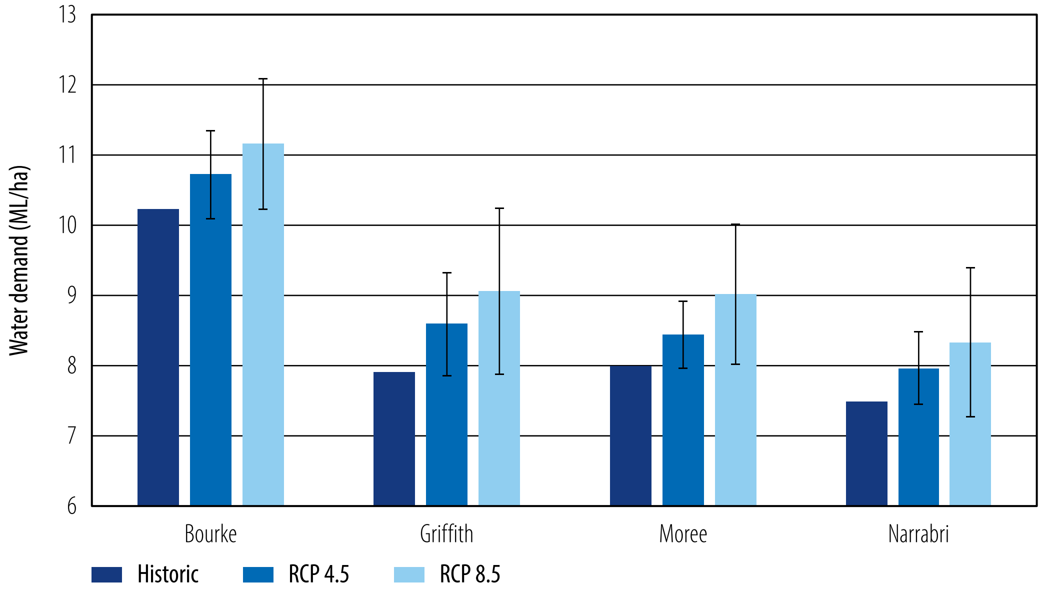


Figure 5 Preliminary maps showing the water demand (ML/ha) under (a) historic, and (b) RCP 4.5 and (c) RCP 8.5 predicted future climates.



Vertical bars represent the standard deviation in the water demand predicted by our MCA model under the 8 global circulation models.

Figure 6 The projected change in water demand at 4 key cotton growing locations.

Summary

The future NSW climate is projected to become more suitable to grow irrigated cotton under both RCP 4.5 and RCP 8.5 emissions scenarios. This change will be greatest in the south of the state. However, to realise these improvements irrigation water will be needed with more than 1 ML/ha additionally required under the RCP 8.5 scenario.

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